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Ground-Water Pollution Problems in the Southeastern United States

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Robert S Kerr Environmental Research Lab, Ada, Okla

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An evaluation of principal sources of ground-water contamination has been carried out in seven southeastern States--Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Virginia. Natural ground-water quality is good to excellent, except for the presence of saline water in some coastal aquifers. Principal sources of man-caused ground water quality problems in order of severity are: surface impoundments, landfills, underground storage of waste fluids and surplus water, leaks and spills, agricultural activities, mining activities, and septic tanks.

This investigation indicates that the cases of ground-water contamination recorded to date and referenced in this report represent only a very small percentage of those that actually exist.

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ABSTRACT

An evaluation of ground-water contamination problems has been carried out in seven states in the southeast: Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina and Virginia. Ground water supplies 46 percent of the total water withdrawn in the region, with the major pumpage in Florida. At least 90 percent of the population of Florida and Mississippi are dependent upon ground water for drinking water supplies.

Natural ground-water quality is good to excellent, except for the presence of saline water in some coastal aquifers. The most common natural water-quality problems are high hardness; high iron content; excessive fluoride concentrations; corrosiveness; and the presence of radionuclides. Principal sources of man-caused ground-water quality problems in order of their severity are: surface impoundments, landfills, underground storage of waste fluids and surplus water, leaks and spills, agricultural activities, mining activities, and septic tanks. Other sources that appear to be of less importance but still must be considered include land disposal of waste waters, miscellaneous unforeseen sources, ground-water development, petroleum development activities, natural bodies of surface water, and highway deicing.

The findings of the investigation indicate that the cases of ground-water contamination recorded to date and referenced in this report represent only a very small percentage of those that actually exist. Basic research is needed on how to improve methods to inventory and correct problems of ground-water contamination and how to prevent future problems through better management and control of activities that can affect ground-water quality.

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SECTION I

CONCLUSIONS

1. Total use of ground water in the seven-state region in 1970 was approximately 20.7 million cu m/d (5.5 billion gpd), with ground water supplying 44 percent of public supply, 89 percent of rural, 34 percent of industrial, and 56 percent of irrigation requirements.

2. The percentage of the population in the study area dependent upon ground water for drinking water supplies is significant, ranging from 30 percent in Virginia to 91 percent in Florida.

3. Ground water can be developed almost anywhere in the region. Areally extensive deposits of sands, gravels, and permeable limestones of considerable thickness are the principal aquifers in the Coastal Plain. Fractured and cavernous limestones and dolomites serve as the major aquifers in other areas.

4. The natural quality of ground water is good to excellent, except for the occurrence of saline water in some coastal aquifers.

5. The most common natural water-quality problems in fresh-water aquifers are high hardness; high iron content; excessive fluoride concentrations; corrosiveness; and the presence of radionuclides.

6. Surface impoundments, which are used for treating, handling, and storing liquid wastes and sludges, are leaking many millions of litres per year of potentially hazardous substances to ground water. The number of lagoons, pits, and basins is expected to increase sharply as industries change over from direct surface-water discharge to land treatment of wastes.

7. Industrial and municipal landfills, covering large tracts of land, are a source of ground-water contamination everywhere in the region. Specific controls on, and sites for, the disposal of hazardous wastes are generally lacking. Most states have little control over industrial disposal sites located on private properties.

8. The utilization of deep injection wells for underground storage of liquid industrial and municipal wastes is expected to increase considerably. However, drainage wells pose a more immediate threat to ground-water quality, particularly in Florida where more than 6,500 such wells are known to exist and receive waters ranging from normal surplus waters to considerably polluted urban storm runoff and sewage waters, as well as a wide variety of other agricultural and industrial fluid wastes.

9. Leaks and spills of hazardous and non-hazardous fluids on and below the land surface have occurred throughout the region. The most commonly spilled or leaked fluids are petroleum products that are in transferral, in transport, or in storage. As reported by well drillers, petroleum products in ground-water supplies is the most common reason for well replacement because of contamination.

10. Ground-water contamination related to agricultural activities occurs primarily from the use of excessive amounts of fertilizers on permeable soils or from the mixing of pesticides near wells. A greater incidence of contamination occurs as a result of termite or pest control practices. In fact, the heavy use of fertilizers and pesticides by home owners and pest control companies in urbanized areas probably has more impact on ground-water quality than traditional agricultural activities.

11. The impact of ground-water contamination from coal-mining activities in Alabama and Virginia has not been assessed. Increased mining will occur in these areas due to the nation's drive for energy self-sufficiency.

12. Ground-water contamination has probably occurred in some of the phosphate-mining areas of Florida, but the problem is just now being evaluated. The contaminant is primarily radium-226 concentrated in acidic gypsum by-product wastes from the wet process of phosphoric acid production.

13. A significant source of ground-water contamination is the discharge of partially treated sewage from septic tank systems. Approximately 13 million people in the region are served by on-site disposal, of which 76 percent of the systems are septic tanks or cesspools. As reported by well drillers in the region, bacterial

contamination by septic tanks is the second most common reason for well replacement. High septic tank density in some suburbanized areas will probably lead to regional nitrate buildup in the ground water.

14. There is potential for ground-water contamination by land disposal of waste waters if the various natural systems operative at disposal sites are not considered as in interactive unit. The assessment of site suitability and design requires the combined effort of multi-disciplined teams of scientist and engineers.

15. Numerous scattered, sporadic, and unforeseen miscellaneous ground-water contamination events with considerable potential for impact on water supplies and public health have occurred throughout the region. Multi-disciplinary emergency task forces available on call are needed to make quick, accurate decisions for clean-up and water-supply protection.

16. Salt-water encroachment in the coastal areas of the region has long been recognized as a threat to fresh-water aquifers. Consequently, the problem is understood and controlled as well as possible.

17. Considerable potential for ground-water contamination occurs as a result of heavy pumping in karst (sinkhole) areas which are subject to surface collapse, causing the introduction of contaminants stored on the surface or providing a conduit for pollutants to enter the aquifer.

18. Flowing fresh-water and saline-water wells do cause gradual salt-water encroachment and contamination of surficial and confined aquifers, not to mention the wastage of water resources. It is estimated that in Florida alone, there are 2,000 to 3,000 flowing wells of poor quality water.

19. The primary contaminant related to petroleum development activities has been the disposal of brines in seepage pits and disposal wells. Unplugged oil test wells have contaminated fresh-water aquifers. A long-term awareness of these problems probably will result in minimal future contamination despite accelerated exploration and development.

20. Collapse of sinkhole lakes due to heavy pumping of underlying aquifers may pose future problems, particularly if such lakes are receiving urban storm runoff and treated sewage waters.

21. Contamination of ground water by dissolved highway de-icing salts is minimal and occurs only in the northern portion of the region.

22. Throughout the region the approach to existing problems is to apply corrective action only after the contamination has been discovered. Anticipation and elimination of potential sources of contamination is not emphasized because of the lack of funding or staffing of the agencies responsible for environmental quality.

23. The case histories reported are only a very small percentage of the instances of ground-water contamination from all sources that exist in the region.

SECTION II

RECOMMENDATIONS

1. The importance of ground water as a source of rural, public, industrial, and irrigation water supply should be promoted through educational and informational programs, emphasizing the need to protect ground-water quality.

2. Attempts must be made on local, state and national levels to reduce the redundancy of agency responsibility and establish a clarification of jurisdiction and responsibility.

3. Increased funding and staffing is recommended for those agencies responsible for defining the hydrogeologic framework of the various states; determining the natural ground-water quality conditions; inventorying of ground-water resources; assesing and controlling ground-water contamination, and enforcing existing regulations.

4. Local agencies (water management districts, river basins, counties, etc.) should be staffed and funded to handle the day-to-day individual local problems of ground-water contamination which may require immediate response.

5. There should be more extensive follow-up on contamination events in terms of: what happened; what needs to be done; what was done; what caused the event; what should be done to prevent the reoccurrence at the site or elsewhere; who was affected by the contamination; and what was the economic loss as a result of cleanup or loss of water supply.

6. Methods of inventorying all existing and potential sources of ground-water contamination should be developed for use on a state-wide basis.

7. Monitoring of suspected sources or contamination should be increased, especially where contaminants from such sources could be extremely detrimental to human health, or in those areas where major or sole water supplies may be threatened.

8. More detailed analyses of water samples obtained from new and existing wells are needed. Selection of criteria for the various parameters measured in such analyses

should take into account the local potential sources of contamination and the most common contaminants associated with them.

9. Particular emphasis should be given to protecting those areas of the southeast underlain by permeable sands and karst (sinkhole) terrane, as they are the most vulnerable to contamination and either contain the largest supplies of ground water or serve as recharge areas for the major aquifers.

SECTION III

INTRODUCTION

This report deals with ground-water pollution problems in the southeastern United States, which comprises the seven states of Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Virginia. Figure 1 shows the location of these states and of other groups of states covered in previous studies of this type. The report contains a general description of the ground-water resources of the region, an overview of the contamination problems, an assessment of the severity of the problems, and recommendations dealing with needs for research and controls.

The following section of this report describes the geologic setting and occurrence of principal aquifers on a state-by-state basis, succeeded by a chapter on the natural ground-water quality. This is followed by a discussion of the principal sources of ground-water contamination in the region. The final section recommends research and other needs required to combat the problems of ground-water contamination, based on the findings of the investigation.

Information on natural water quality and aquifer systems was obtained from a review of literature on the region. The published data were also surveyed in an effort to obtain data on specific cases of ground-water contamination. However, few of the known instances of contamination have been reported in the literature. In order to gain a perspective on the status of ground-water contamination, it was necessary to contact, mostly by personal visit, public officials, consultants, scientists, and others involved in water supplies so that their files and individual experiences and knowledge could be applied to the study.

Throughout the report the terms "contamination" and "pollution" are used to mean the degradation of the natural quality of ground water as a result of man's activities. Contamination may impair the use of the water or may create hazards to public health through toxic substances or the spread of disease. A contaminant as defined by the Safe Drinking Water Act is - "any physical, chemical, biological, or radiological substance or matter in water". Increases in concentrations of mineral constituents as the natural result of movement of ground water through an aquifer are referred to as mineralization.

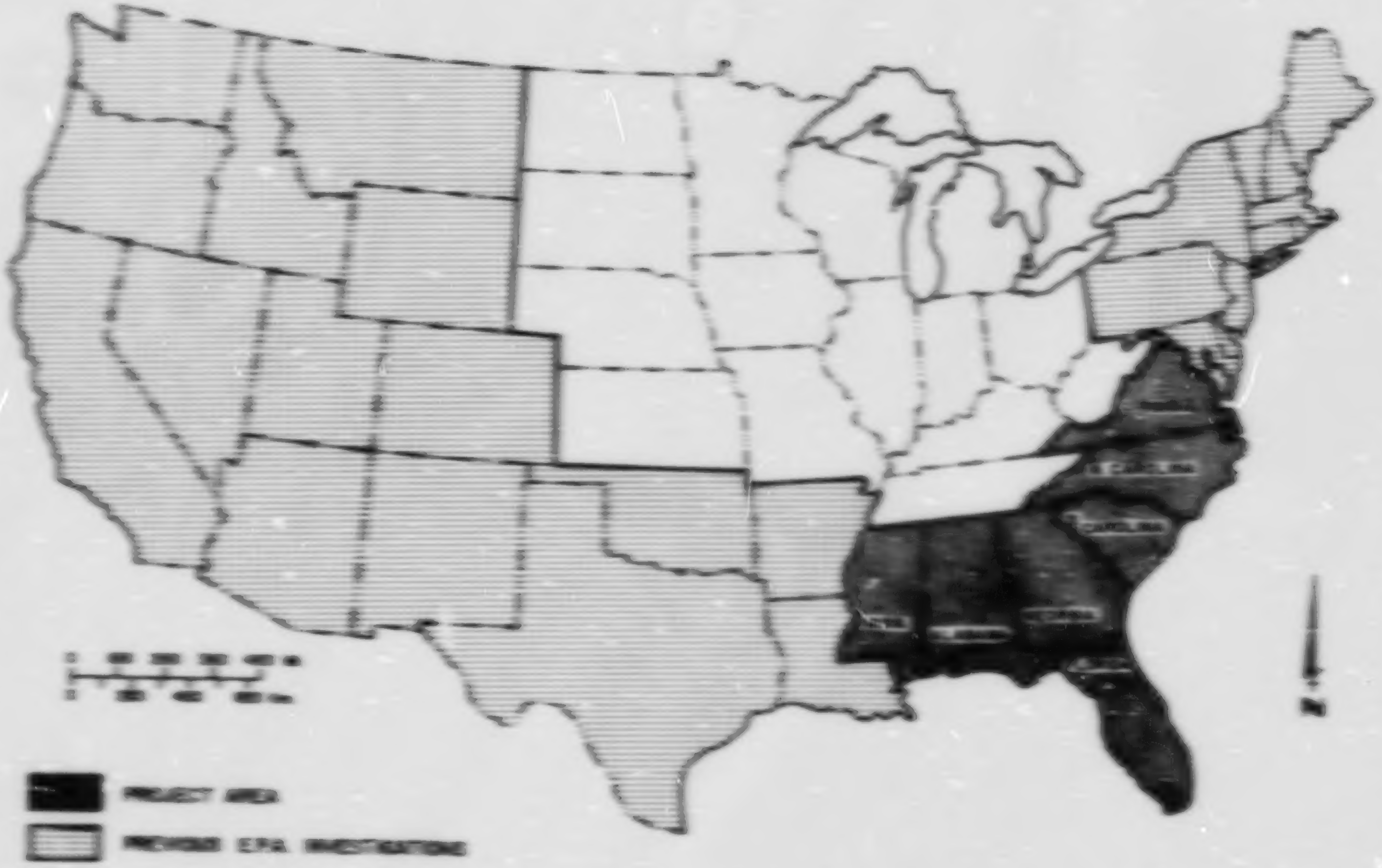
PROJECT AREA
PREVIOUS EPA INVESTIGATIONS
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Figure 1. Location of states in the southeast project area and previous EPA investigations.

Management and protection of the ground-water resources are of the utmost importance because whereas pollution of surface-water supplies is readily detected and often quickly corrected, pollution of ground water is often not detected until part of an aquifer system has been adversely affected. Once an aquifer is polluted, it takes a considerable period of time and great financial expenditure to alleviate the problem. Often the damage cannot be undone and on occasion the water source has to be abandoned. For these reasons national and state laws and regulations to protect ground-water reservoirs have been and are being adopted, following recommendations along these lines made by Federal, state and private organizations.[1,2,3] A more thorough understanding of natural ground-water quality and ground-water pollution problems existing in the various regions of the nation is needed. The Environmental Protection Agency has undertaken the task of gathering this information, and reports dealing with ground-water pollution have been issued for the south-western states, the south-central states, the northeastern states, and the northwestern states (Figure 1).[4,5,6,7]

USE OF GROUND WATER

Almost one-half of the population of the United States is dependent on ground water for drinking purposes. About 94 percent of the rural population and 37 percent of the population served by public water-supply systems obtain their water from ground-water sources. This is because it is generally more economical to install wells than to pipe water from a surface-water body and provide the necessary treatment. Also, many sources of surface water are unreliable and the large tracts of land required for construction of new surface-water reservoirs are becoming scarce and costly to obtain.

The estimated use of fresh surface and ground water in the seven states of the project area in 1970 for public supply, rural supply, and industrial and irrigation purposes was in excess of 45 cu hm/d or 11.9 bgd.[8] Table 1 shows the breakdown of the estimated fresh-water use on a state-by-state basis. Figure 2 is a graph of the ground-water use for the above purposes for each of the states. Figure 3 is a comparison of the percent surface and ground water used for all purposes in each state.

As can be seen in the table and figures, the range in water use is from 2,771 cu hm/d (0.732 bgd) in South Carolina to 16,056 cu hm/d (4,242 bgd) in Florida. The reliance on ground-water sources is 17 percent in Alabama to 70 percent in Florida. Use of ground water for public supply ranged

TABLE 1. ESTIMATED USE OF WATER IN THE SOUTHEAST UNITED STATES IN 1970.[b]
(partial figures may not add up to totals because of rounding)

State	Public Supply		Rural a/		Industrial b/		Irrigation		Total	
	1,000 m³/d	mgd	1,000 m³/d	mgd	1,000 m³/d	mgd	1,000 m³/d	mgd	1,000 m³/d	mgd
ALABAMA										
Ground water	379	100	280	76	252	66	20	5.6	1,039	274.6
Surface water	1,382	365	57	15	3,444	912	45	12.0	4,889	1,297.0
Total:	1,762	465	345	91	3,796	1,003	65	17.6	5,948	1,571.4
Percent ground water	22		84		7		31		17	
FLORIDA										
Ground water	2,677	707	481	127	2,687	710	4,922	1,300.0	11,166	2,950.0
Surface water	454	120	45	12	719	190	3,671	970.0	4,890	1,292.0
Total:	3,131	827	526	139	3,406	900	8,592	2,270.0	16,056	4,242.0
Percent ground water	85		91		79		57		70	
GEORGIA										
Ground water	719	190	379	100	1,249	330	25	6.6	2,372	626.6
Surface water	1,325	350	5	1.4	1,136	300	151	40.0	2,617	691.4
Total:	2,044	540	384	101.4	2,385	630	176	46.6	4,989	1,318.0
Percent ground water	35		99		52		14		48	

a/ Domestic and livestock use

b/ Saline water and thermoelectric-power water use excluded

Table 1 (cont.) ESTIMATED USE OF WATER IN THE SOUTHEAST UNITED STATES IN 1970.[a]
(partial figures may not add up to totals because of rounding)

State	Public Supply		Rural[b]		Industrial[c]		Irrigation		Total	
	1,000 m³/d	mgd	1,000 m³/d	mgd	1,000 m³/d	mgd	1,000 m³/d	mgd	1,000 m³/d	mgd
MISSISSIPPI										
Ground water	606	160	151	40	1,173	310	833	220.0	2,763	730.0
Surface water	116	30	91	24	719	190	606	160.0	1,529	404.0
Total:	722	190	242	64	1,892	500	1,439	380.0	4,292	1,134.0
Percent ground water	84		62		62		58		64	
NORTH CAROLINA										
Ground water	303	80	606	160	530	140	189	50.0	1,628	430.0
Surface water	1,438	380	28	7.4	1,817	480	121	32.0	3,404	899.4
Total:	1,741	460	634	167.4	2,347	620	310	82.0	5,032	1,329.4
Percent ground water	17		96		23		61		32	
SOUTH CAROLINA										
Ground water	208	55	189	50	201	53	34	8.9	632	166.9
Surface water	908	240	19	4.9	1,136	300	76	20.0	2,138	564.9
Total:	1,116	295	208	54.9	1,337	353	110	28.9	2,770	731.8
Percent ground water	19		91		15		31		23	

Table 1 (cont.) ESTIMATED USE OF WATER IN THE SOUTHEAST UNITED STATES IN 1970.[a]
(partial figures may not add up to totals because of rounding)

State	Public Supply		Rural[b]		Industrial[c]		Irrigation		Total	
	1,000 m^3/d	mgd	1,000 m^3/d	mgd	1,000 m^3/d	mgd	1,000 m^3/d	mgd	1,000 m^3/d	mgd
VIRGINIA										
Ground water:	280	76	318	84	454	120	20	5.2	1,072	283.2
Surface water:	1,211	320	72	19	3,482	920	114	30.0	4,879	1,289.0
Total:	1,491	396	390	103	3,936	1,040	134	35.2	5,951	1,572.2
Percent ground water	19		82		12		15		18	
GRAND TOTAL										
Ground water:	5,652	1,429	2,622	690	6,646	1,756	6,042	1,596.1	20,672	5,461.1
Surface water:	6,823	1,800	317	83.7	12,456	3,290	4,784	1,264.0	24,666	6,437.7
Total:	12,465	3,229	2,939	773.7	19,102	5,046	10,826	2,860.1	45,336	11,898.8
Percent ground water	46		89		34		56		46	

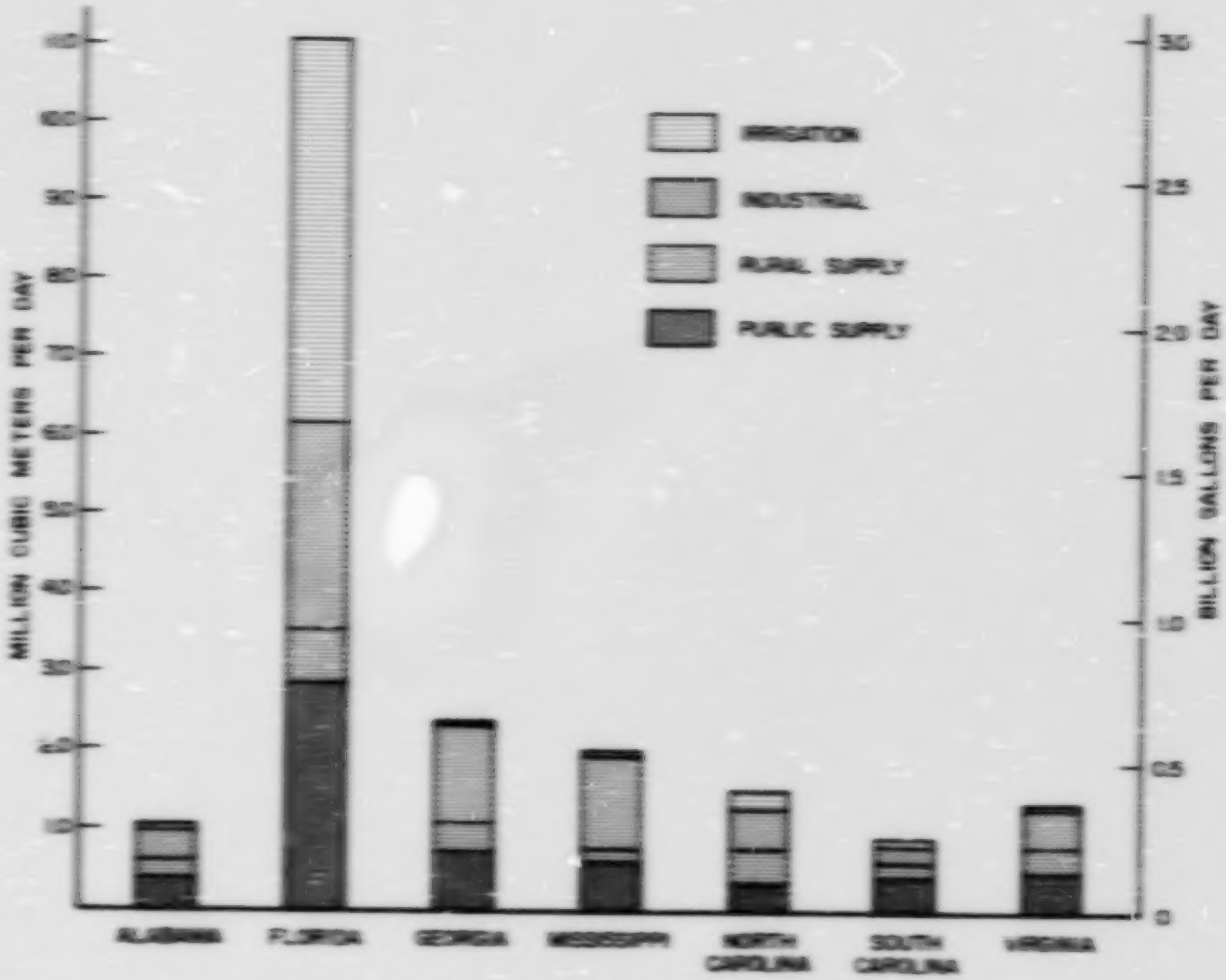

Figure 2. Use of ground water in 1970.[8]

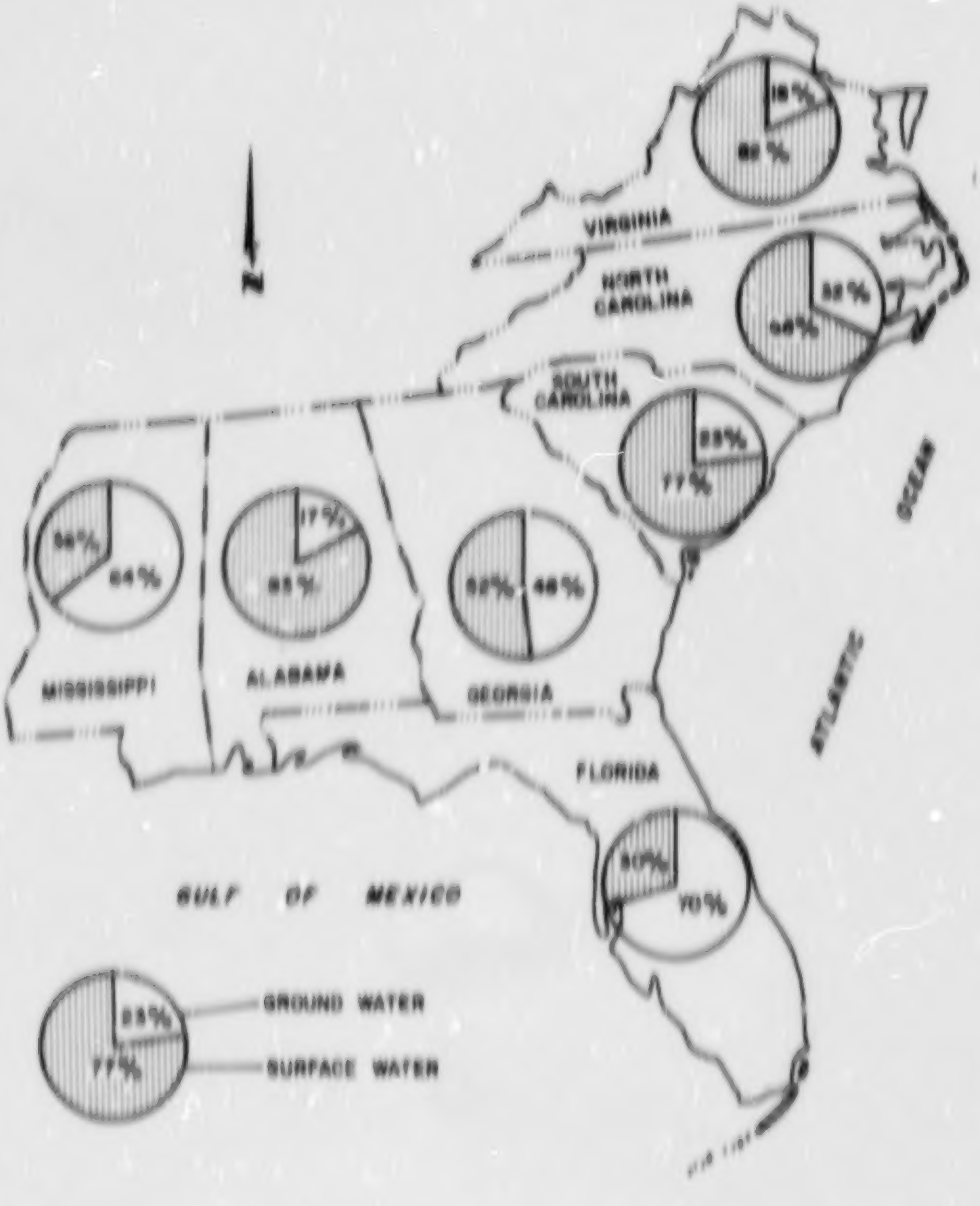
N
18%
82%
VIRGINIA
NORTH CAROLINA
32%
68%
SOUTH CAROLINA
23%
77%
36%
64%
17%
83%
52%
48%
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
30%
70%
ATLANTIC OCEAN
GULF OF MEXICO
23%
77%
GROUND WATER
SURFACE WATER

Figure 3. Comparison of ground-water use to surface-water use in 1970.8)

from 0.208 cu hm/d (0.055 bgd) in South Carolina to 2.877 cu hm/d (0.760 bgd) in Florida.[8] Except for Florida and Mississippi, the use of surface water for all purposes is greater than that of ground water.

However, the percentage of the population dependent upon ground water for drinking water supplies in the study area is significant. Figure 4 shows the percent of the total population relying on either source for this purpose, with ground-water use ranging from 30 percent in Virginia to 91 percent in Florida.

In the region, over 34 percent of the total water withdrawn from all sources for domestic use by public-supply systems in 1970 was obtained from ground-water sources. The percentage of use on a state basis ranged from 10 percent in Virginia to over 72 percent in Florida.[9] A report on water use by 138 selected municipalities in Florida for 1970 shows that 119 relied entirely upon ground water. The systems involved serve 64 percent of the State's population.[10]

Some of the major cities in the region that rely entirely on ground water for supply include Montgomery, Alabama; Jacksonville, Miami, and St. Petersburg, Florida; and Savannah, Georgia.[11] Many other municipalities have a combination of surface-water and ground-water systems for their source of supply.

Rural areas rely heavily on ground-water sources for domestic supply and livestock watering. The use of ground water for this purpose ranges from 63 percent in Mississippi to 98 percent in Georgia. Although slightly under the national average of 94 percent, the dependence of the rural population on ground water is still very high, about 87 percent.

Statistics on ground-water use by self-supplied industries are scanty, but the 1970 compilation (Table 1) shows a total of 5.66 cu hm/d (1.76 bgd).[8] The portion of self-supplied industrial water from ground-water sources ranges from 9 percent in Alabama to 79 percent in Florida. Over 50 percent of the total industrial water in two other states, Georgia and Mississippi, is from ground-water sources. Many large manufacturing plants either are located beyond the service areas of public utilities or require such large quantities of high-quality water that they are obliged to develop their own independent water sources. In many cases, ground water is the only readily available supply of water.

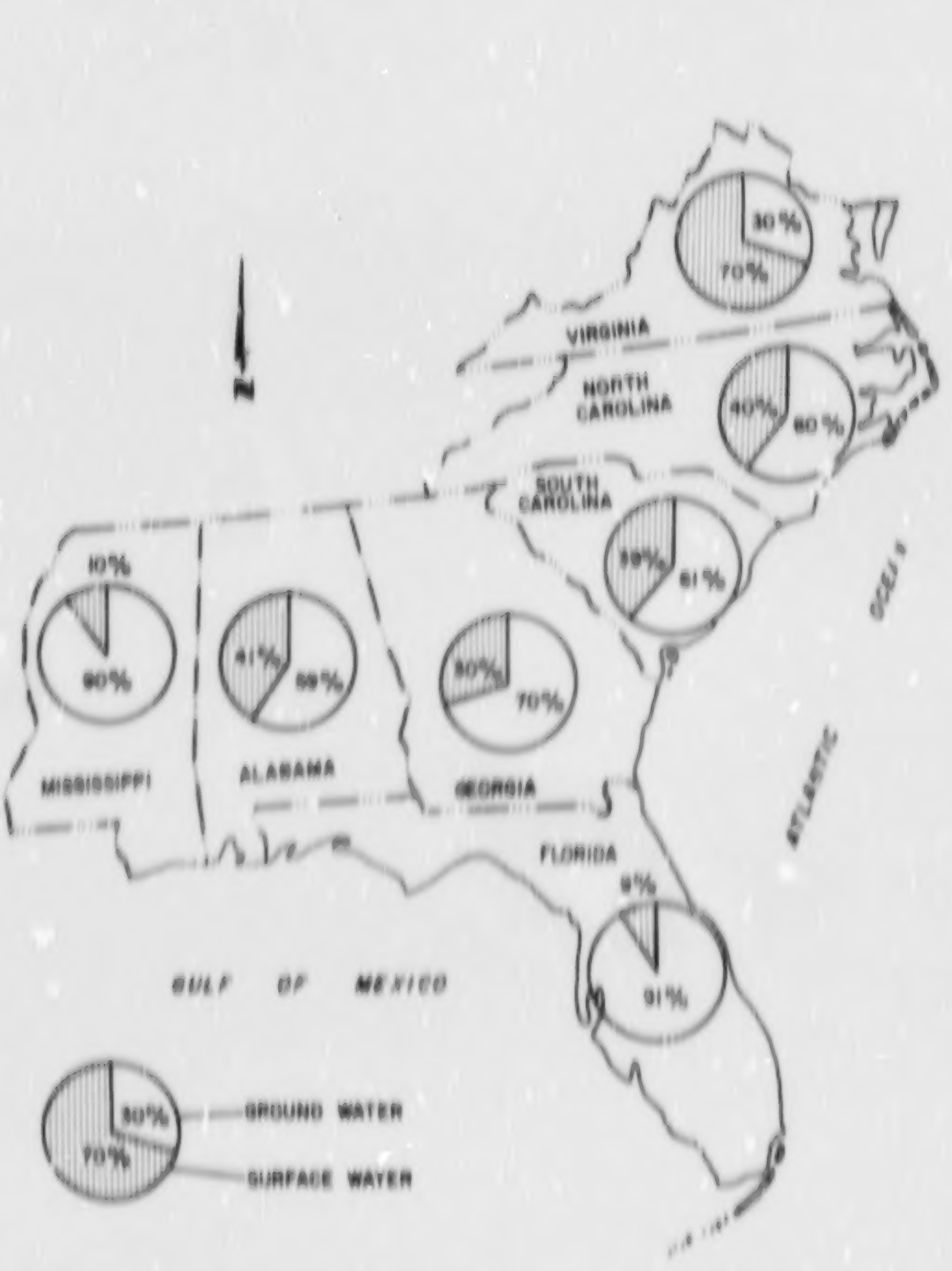
N
VIRGINIA
30%
70%
NORTH CAROLINA
40%
60%
SOUTH CAROLINA
39%
61%
MISSISSIPPI
10%
90%
ALABAMA
41%
59%
GEORGIA
30%
70%
FLORIDA
9%
91%
ATLANTIC OCEAN
GULF OF MEXICO
30%
70%
GROUND WATER
SURFACE WATER

Figure 4. Percent of total population relying on ground water versus surface water for drinking water supply.[9]

By far the largest single use of ground water in the study area is for irrigation in Florida. The estimated use in 1970 was 4.9 cu hm/d (1.3 bgd), more than one and one-half times greater than the public supply use. Groung water used for irrigation ranged from 14 percent of the total in Virginia to 61 percent in North Carolina.

PROJECTIONS OF GROUND-WATER USE

The demand for ground water for municipal, self-supplied industrial, and agricultural use is expected to increase significantly. The historical and projected trends of fresh-water withdrawal rates in the United States from 1900 to the year 2020 are given in Table 2.[3,8,12,13,14] The projected trend indicates a steady increase in the ground-water use of over 214 percent between 1970 and 2020. The total fresh-water withdrawal by 2020 is expected to be 2,895.5 cu hm/d (765 bgd) of which about 548.9 cu hm/d (145 bgd) will be ground water.

The total water use on a per capita basis is expected to increase from 6.0 cu m/d (1,577 gpd) in 1970 to 8.2 cu m/d (2,155 gpd) in 2020. Although the actual personal consumption of water is not expected to increase, the expansion of industries and utilities will create a significant increase in demand for water. Cooling water demands for electric generating plants will represent the single most significant increase in water demand.

A comparison of ground-water use for the years 1965 and 1970 in the study area is given in Table 3. Total use increased from 15,777 cu hm/d (4,703 bgd) in 1965 to 20,761 cu hm/d (5.461 bgd) in 1970.[8,15] The percentage of increase ranged from four percent in North Carolina to 42 percent in Virginia. Total withdrawal of ground water in the United States increased from 60 bgd in 1965 to 68 bgd in 1970. This represents an overall increase of 11.7 percent. Five of the seven states, namely Alabama, Georgia, Mississippi, South Carolina, and Virginia, surpassed the national average.

Table 2. HISTORICAL AND PROJECTED TRENDS IN FRESH WATER WITHDRAWAL RATES IN THE UNITED STATES. 1,8,12,13,14)

Year	Total U.S. Population millions	Total Fresh Water Withdrawn cu hm/d	bgd	Total Fresh Ground Water Withdrawn cu hm/d	bgd	Total Per Capita Withdrawal cu m/d	gpd
1900	76.0	152.2	40.2	27.6	7.3	2.0	529
1910	92.0	251.3	66.4	44.3	11.7	2.7	722
1920	105.7	346.3	91.5	59.8	15.8	3.3	866
1930	122.8	418.2	110.5	68.9	18.2	3.4	900
1940	131.7	508.7	134.4	85.5	22.6	3.9	1,036
1950	150.7	734.2	194.0	127.2	33.6	4.9	1,287
1960	178.5	1,023.5	270.4	190.8	50.4	5.1	1,344
1970	203.2	1,212.7	320.4	255.1	67.4	6.0	1,577
1980	230.9	1,409.5	372.4	310.0	81.9	6.1	1,613
1990	266.2	1,736.9	458.9	358.1	94.6	6.6	1,724
2000	300.4	2,075.3	548.3	416.3	110.0	6.9	1,825
2010	338.0	2,485.6	656.7	481.1	127.1	7.4	1,943
2020	355.0	2,895.5	765.0	547.3	144.6	8.2	2,155

Table 3. GROUND-WATER USE, 1965 to 1970.[8,15]

State	1965		1970		Percent of Increase Over 1965
	1,000 cu m/d	mgd	1,000 cu m/d	mgd	
Alabama	743	196.3	1,039	274.4	40
Florida	10,087	2,665	11,165	2,950	11
Georgia	2,123	561	2,372	626.6	12
Mississippi	2,021	534	2,763	730	37
North Carolina	1,571	415.1	1,628	430	4
South Carolina	496	131	632	166.9	27
Virginia	757	200.1	1,072	283.2	42
TOTAL	15,777	4,702.5	20,671	5,461.1	

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SECTION III

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SECTION IV

DESCRIPTION OF PROJECT AREA

The project area, which covers the seven states of Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Virginia, has an area of roughly 884,000 sq km (349,000 sq mi), representing 11 percent of the total land surface of the conterminous United States (Figure 1). The project area is characterized by a wide variety of land-form features. Elevations of the land surface range from sea level along the Atlantic and Gulf coasts to over 2,037 m (almost 6,700 ft) in the Blue Ridge Mountains of North Carolina.

PHYSIOGRAPHY

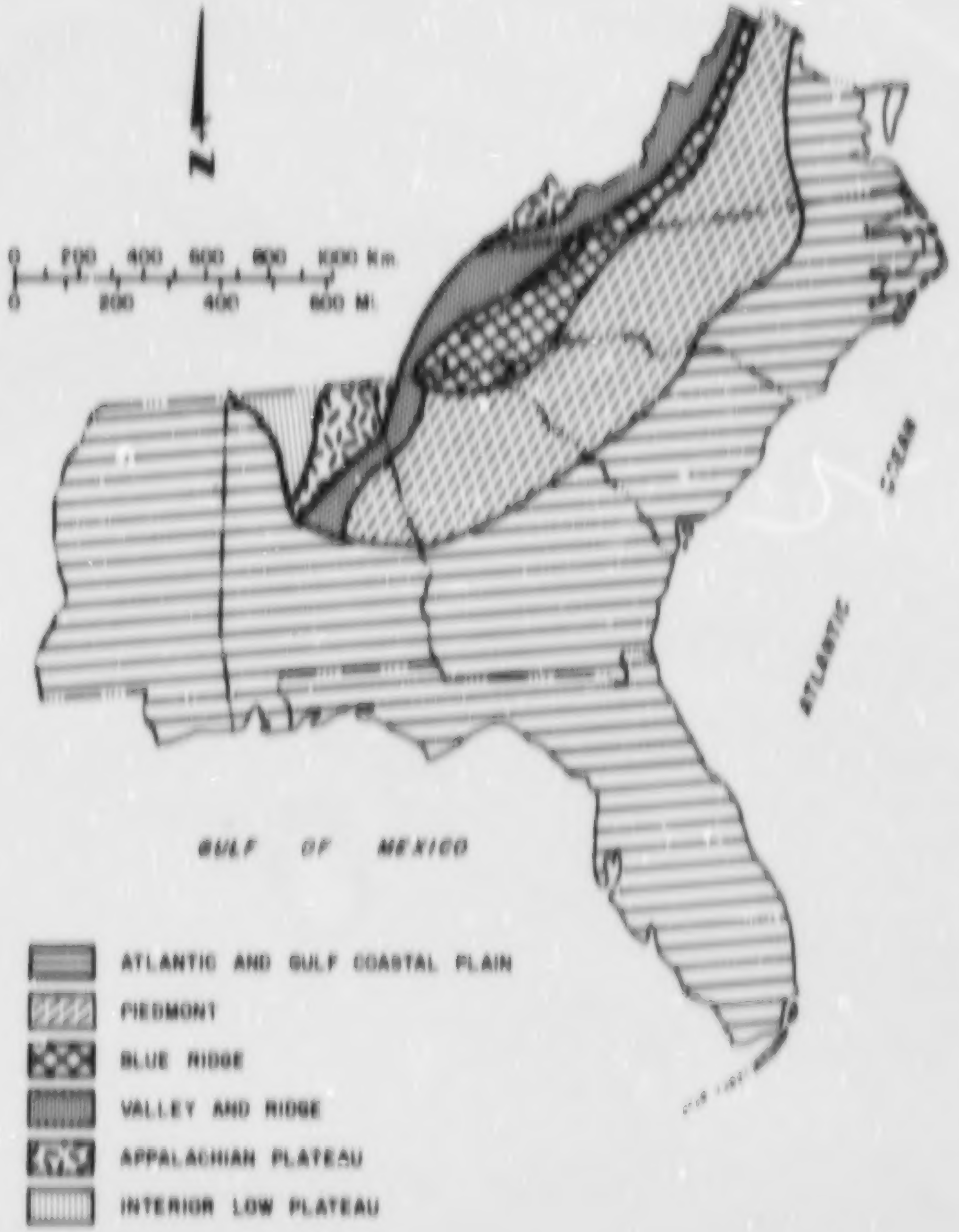
The major physical divisions in the southeast area include the Atlantic and Gulf Coastal Plain, the Piedmont, the Blue Ridge, the Valley and Ridge, and small portions of the Appalachian Plateau and the Interior Low Plateau. Figure 5 shows the limits of these physiographic provinces in the study area.1,2,3)

A classification devised by Thomas divides the continental United States into 10 ground-water regions.4) Based on this system, the study area includes portions of three of these regions (Figure 6):

1. Coastal Plain Region
2. Unglaciated Appalachian Region
3. Unglaciated Central Region

The Atlantic and Gulf Coastal Plain physiographic province is characterized by a seaward-dipping sequence of mostly unconsolidated gravel, sand, silt, clay, marl, and limestone, of Cretaceous to Quaternary age. These materials form a wedge that thickens toward the coast. The surface relief is very moderate with topographic highs rarely exceeding 100 m (328 ft) above sea level.

The Coastal Plain ground-water region, coinciding with the Coastal Plain physiographic province, contains abundant supplies of both surface and ground water. Areally extensive deposits of sands, gravels, and permeable limestones of considerable thicknesses are found in the region. Large amounts of ground water can be obtained from individual wells throughout the entire region.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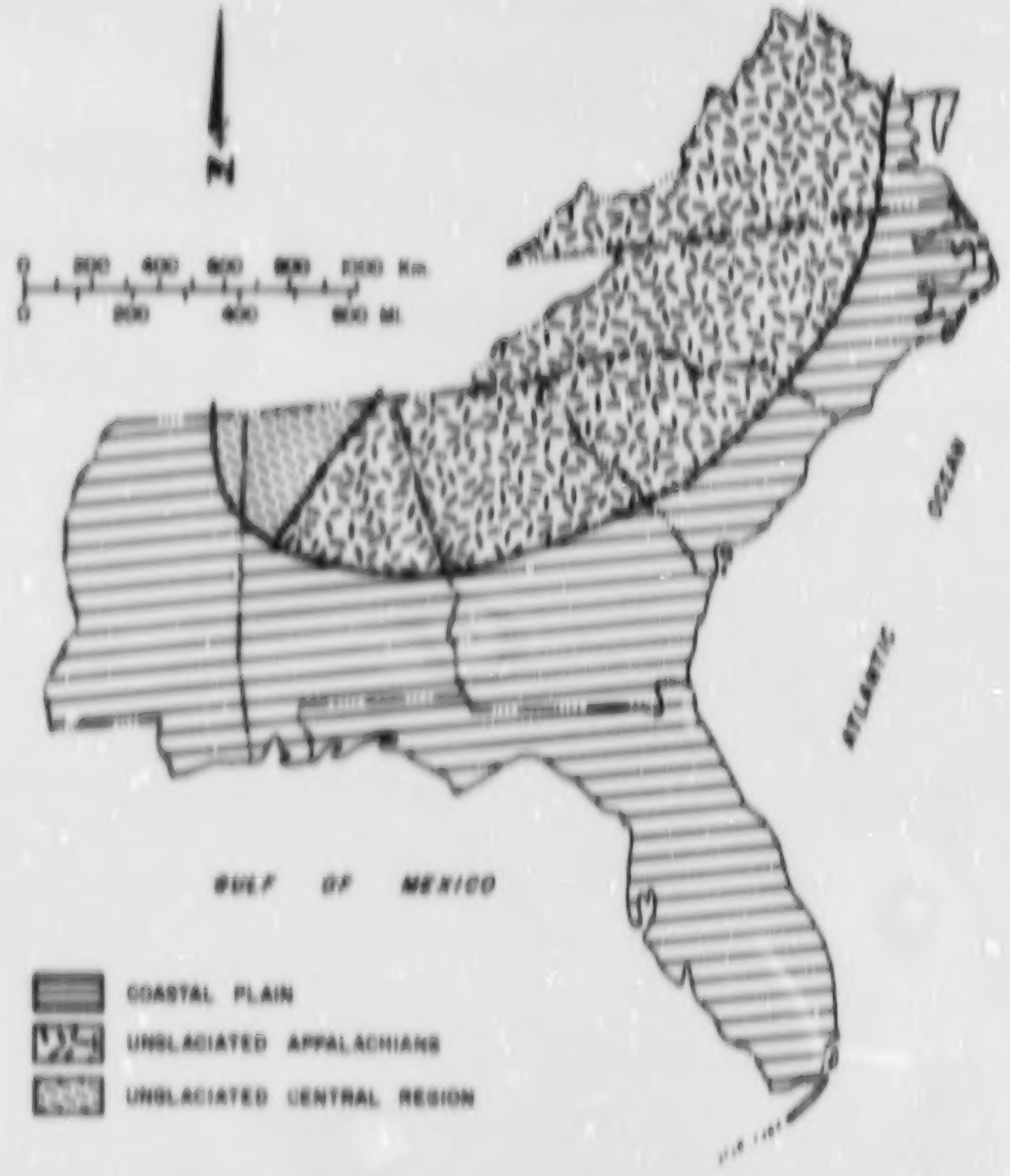
ATLANTIC OCEAN
ATLANTIC AND GULF COASTAL PLAIN
PIEDMONT
BLUE RIDGE
VALLEY AND RIDGE
APPALACHIAN PLATEAU
INTERIOR LOW PLATEAU

Figure 5. Physiographic provinces of the southeastern states.1,2,3)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ATLANTIC OCEAN
GULF OF MEXICO
COASTAL PLAIN
UNGLACIATED APPALACHIANS
UNGLACIATED CENTRAL REGION

Figure 6. Ground-water regions in the southeast United States.4)

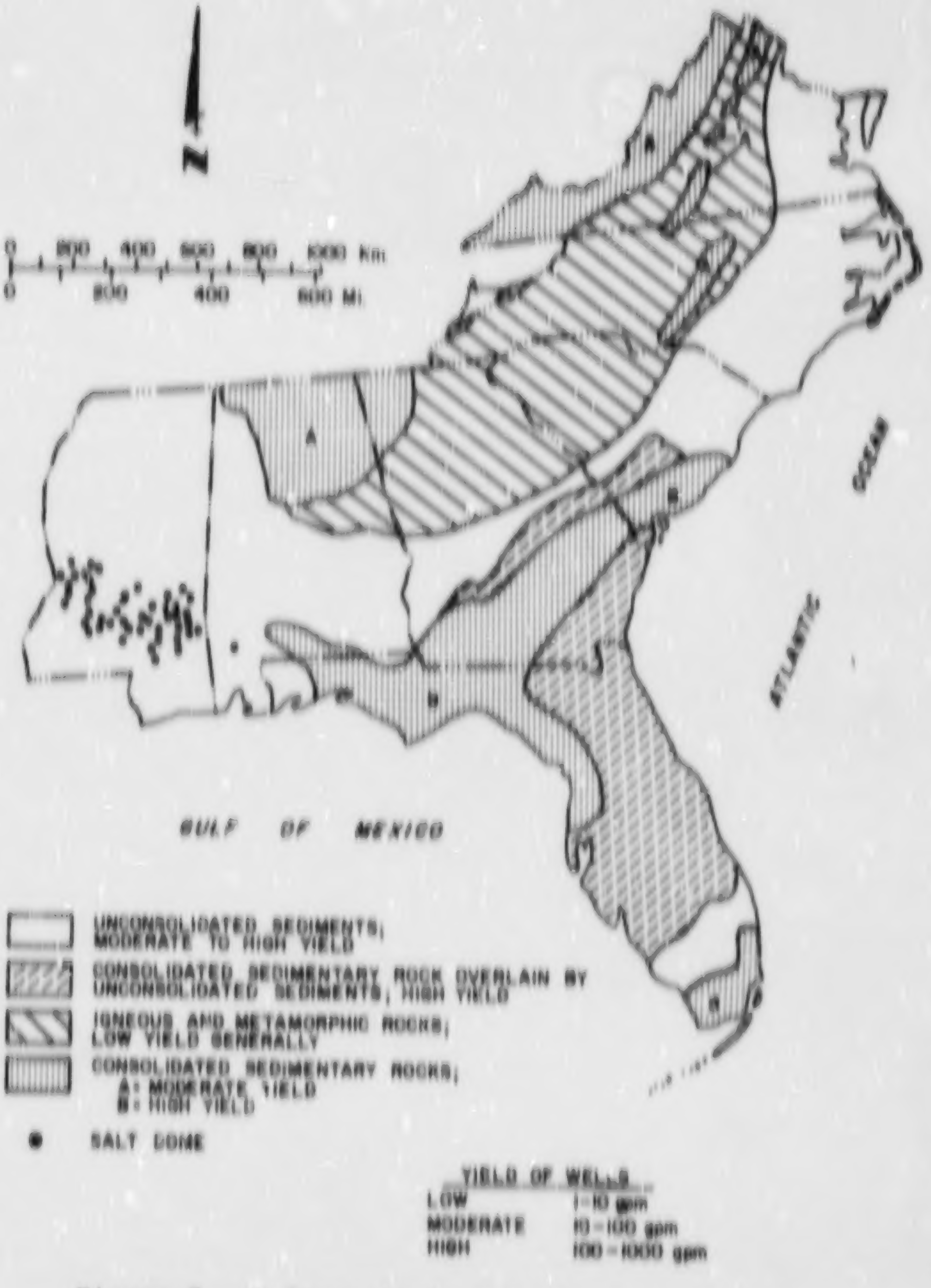
The Unglaciated Appalachian ground-water region is characterized by mountains and hilly uplands separated by broad valleys. Portions of various physiographic provinces are included in the region. From east to west these are: the Piedmont, the Blue Ridge, the Valley and Ridge, and the Appalachian Plateau.

The Piedmont physiographic province is composed of metamorphic rocks intruded by masses of igneous rocks. The yield to wells in the province is generally very low because of the relatively low permeabilities of the rocks. Ground water moves principally along fractures or through the weathered zones. The water-yielding capabilities of the rocks of the Blue Ridge physiographic province are similar to those of the Piedmont province. However because of the sharp relief of the region, increased surface runoff results in less infiltration or recharge to the aquifer.

The Valley and Ridge physiographic province is characterized by folded rocks, principally limestone associated with sandstone and shale. The region is generally more productive from a ground-water viewpoint than either the Piedmont or Blue Ridge provinces. Large springs and high-yielding wells occur locally in the limestone, where it is very fractured and cavernous. The uppermost limestones and sandstones of the Appalachian Plateau physiographic province are fairly productive, but such aquifers are not very extensive because of deep dissection of the land due to erosion of the elevated plateaus.

A small portion of the Unglaciated Central ground-water region extends into northwestern Alabama and northeastern Mississippi. There, the rocks are characteristically horizontal or slightly dipping sedimentary rocks, overlain locally by unconsolidated stream sediments or thick zones of weathered chert. Limestones and sandstones serve as the principal aquifers. Large springs and high-yielding wells are scattered throughout the region.

General hydrogeologic conditions in the project area are shown on Figure 7. The map shows the general type of rock material and gives the approximate range in ground-water yield for each. Additionally, it shows the location of salt domes which locally affect the maximum depth of fresh water. The map also differentiates between the moderately-yielding carbonates and sandstone aquifers of the northern portion of the area and the high-yielding carbonates of Florida, southern Georgia, and South Carolina.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GULF OF MEXICO
ATLANTIC OCEAN
UNCONSOLIDATED SEDIMENTS; MODERATE TO HIGH YIELD
CONSOLIDATED SEDIMENTARY ROCK OVERLAIN BY UNCONSOLIDATED SEDIMENTS; HIGH YIELD
IGNEOUS AND METAMORPHIC ROCKS; LOW YIELD GENERALLY
CONSOLIDATED SEDIMENTARY ROCKS; A: MODERATE YIELD B: HIGH YIELD
SALT DOME
YIELD OF WELLS
LOW 1-10 gpm
MODERATE 10-100 gpm
HIGH 100-1000 gpm

Figure 7. Hydrogeologic map of the southeast United States.5,6,7)

POPULATION

According to the 1970 Census, approximately 29.4 million or about 14.5 percent of the nation's 203.2 million people live in the report area (Table 4). The rural population exceeds 50 percent in three states: Mississippi, North Carolina, and South Carolina. A high concentration of population in urban areas is found in Florida, followed by Virginia, Georgia, and Alabama. The growth rate of the seven states combined was 14 percent between 1960 and 1970.[8]

CLIMATE

The climate of the seven-state region is influenced by a number of factors: proximity to the Gulf of Mexico or the Atlantic Ocean, latitude, elevation, and topography. The presence of the large bodies of water tends to lower summer temperatures and raise winter temperatures along the coast. Inland, however, the summers are hotter and the winters cooler. In no case can the winters be described as severe.

The region is affected by invasions of cool, dry air from the interior or of mild, moist air from the Gulf of Mexico or the Atlantic Ocean. Hot, humid summers occur throughout most of the area, especially in the interior lowlands and the south.

Precipitation is fairly well distributed throughout the year in all of the region except for Florida, where most of the rain occurs during the period from June to October. Figure 8 is a map showing the distribution of the average annual precipitation in the area. Snowfall in the area ranges from unusual in Florida to an average of 1,270 mm (50 in.) in the mountains of North Carolina. Hurricanes have occurred in all of the seven states, but most commonly in the more southern states.

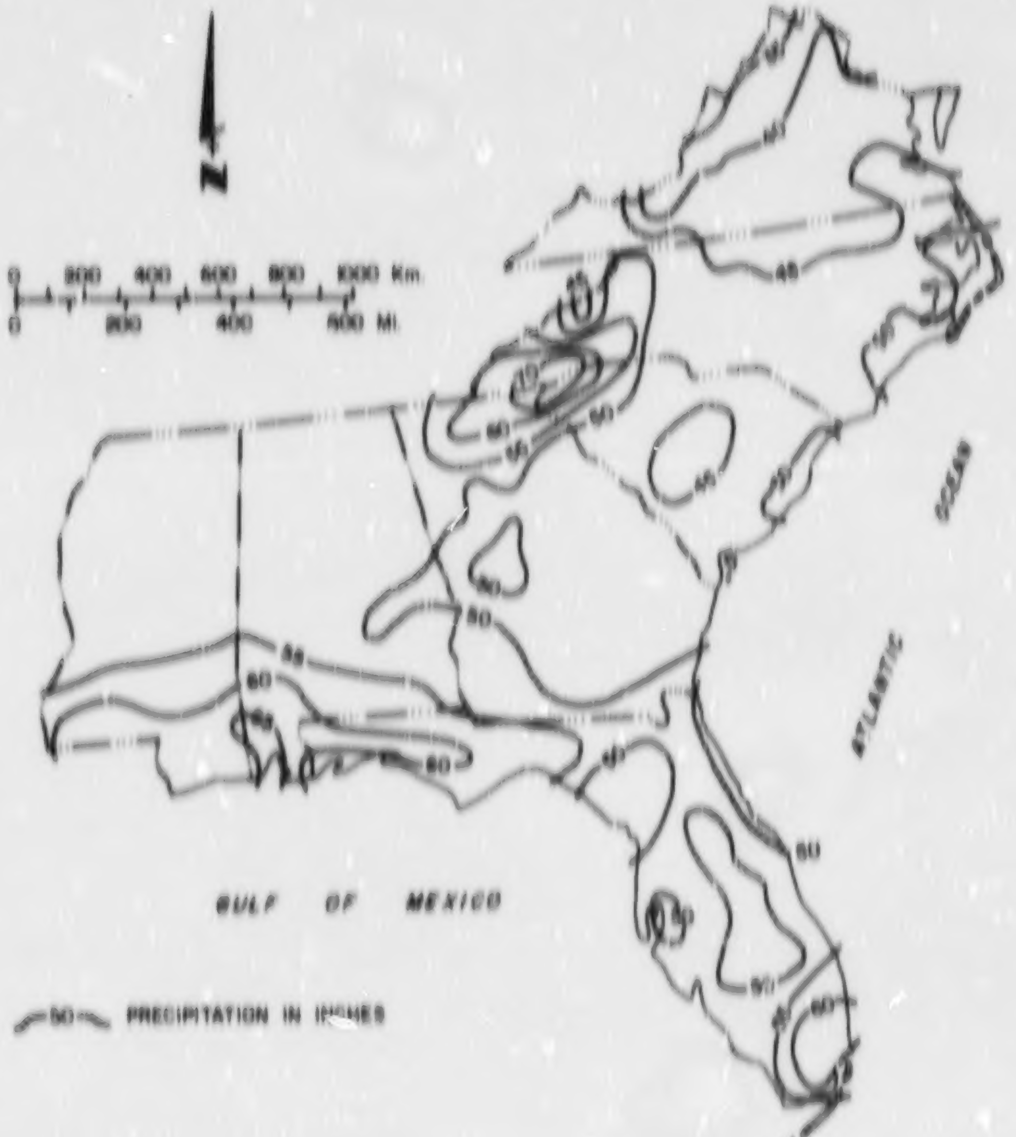
The average annual evaporation from open water surfaces ranges from 762 mm (30 in.) in the northern portion to 1,372 mm (54 in.) in the south (Figure 9). Only in a small part of Florida does the evaporation equal or exceed the average precipitation.

GEOLOGY AND GROUND-WATER RESOURCES

The following is a discussion of the general geology in relation to the ground-water resources on a state-by-state basis. Where the water-bearing characteristics of the aquifers are known, they are included to allow a more complete picture of the system. Because it is beyond the scope

Table 4. POPULATION CHARACTERISTICS

State	1970 Population	Percent Increase 1960 to 1970	Centers of between 50,000 & 100,000 Population	Centers of over 100,000 Population	Population distribution (percent) Urban	Rural
Alabama	3,444,165	5.4	2	4	58.4	41.6
Florida	6,789,443	37.1	6	8	80.5	19.5
Georgia	4,589,575	16.4	2	4	60.3	39.7
Mississippi	2,216,912	1.8	None	1	44.5	55.5
N. Carolina	5,082,059	11.5	4	4	45.0	55.0
S. Carolina	2,590,516	8.7	2	1	47.6	52.4
Virginia	4,648,494	17.2	3	8	63.1	36.9
Total:	29,361,164	14.0	19	30		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GULF OF MEXICO
ATLANTIC OCEAN
50 PRECIPITATION IN INCHES
45
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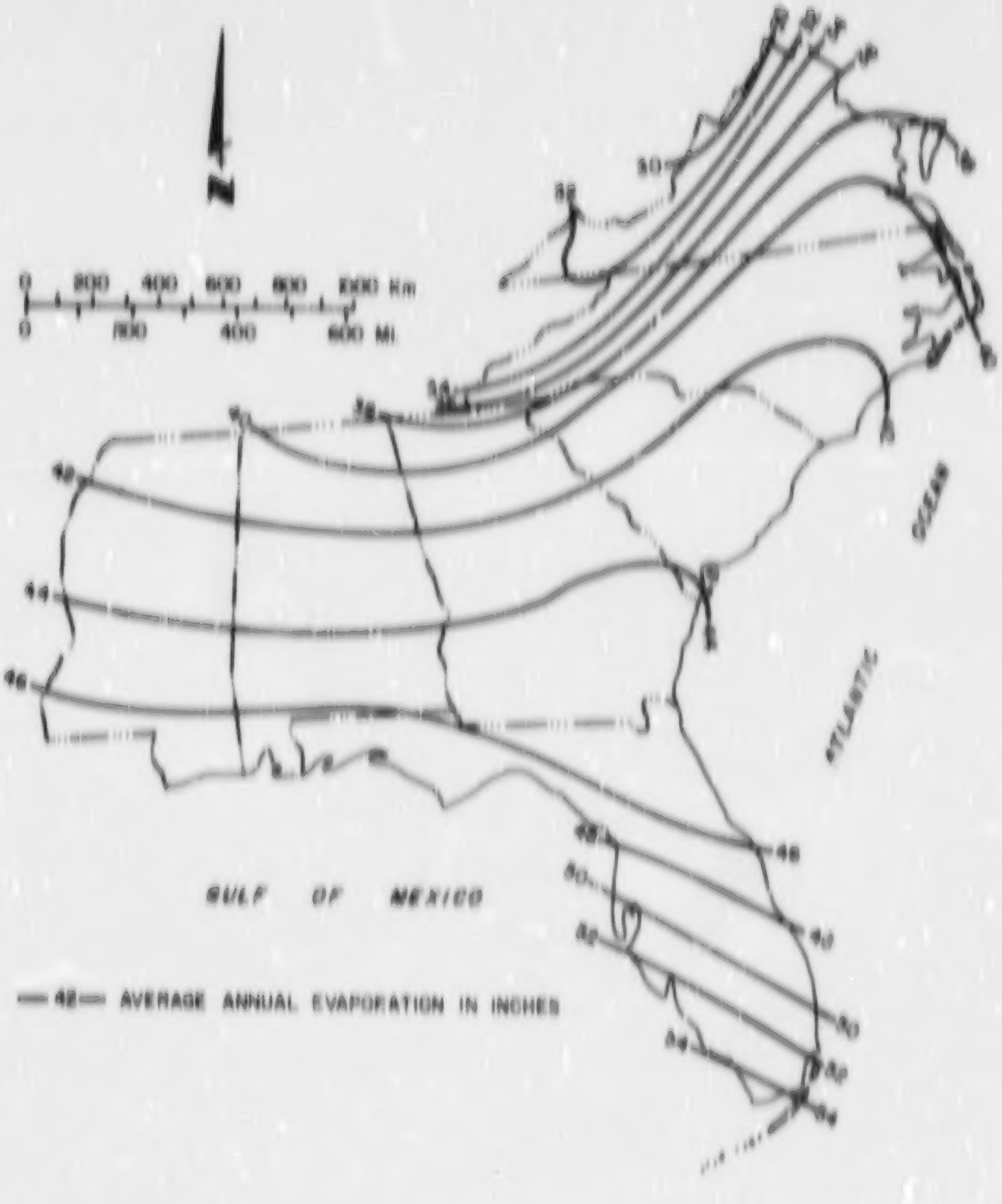
55
60
80

Figure 8. Average annual precipitation.9)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GULF OF MEXICO
ATLANTIC OCEAN
—42— AVERAGE ANNUAL EVAPORATION IN INCHES

Figure 9. Average annual evaporation from open water surfaces.9)

of this study to present a detailed breakdown of the geology and the aquifer properties, the statements are generalized and specific references are given in the event that additional information is desired.

Alabama

Alabama lies in parts of five physiographic provinces and three ground-water regions. The physiographic provinces are: the Interior Low Plateau, the Appalachian Plateau, the Valley and Ridge, the Piedmont, and the Coastal Plain (Figure 5). The ground-water regions are the Unglaciated Central region, the Unglaciated Appalachians region, and the Coastal Plain region (Figure 6).

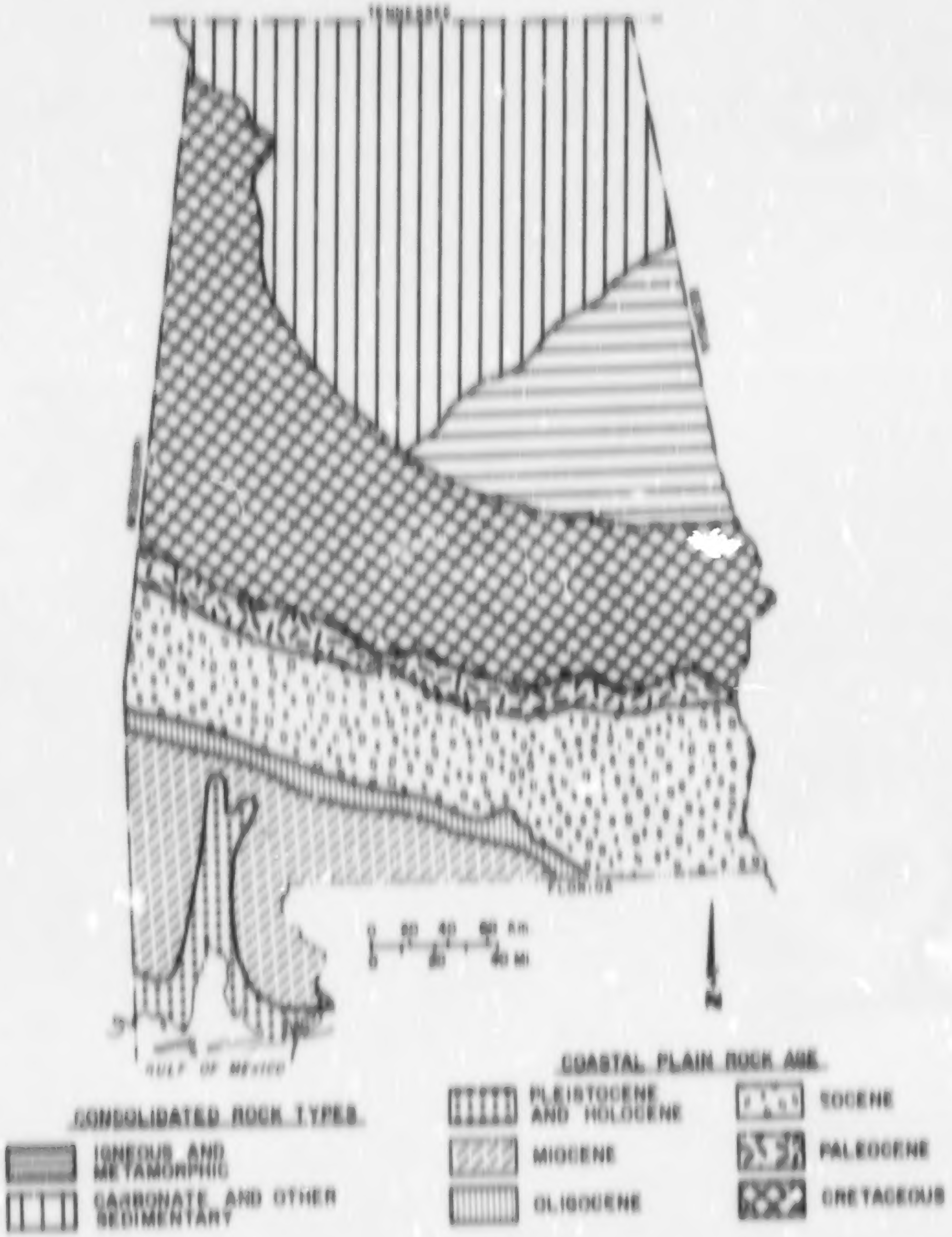
There are four basic rock types that serve as aquifers in Alabama: the igneous and metamorphic rocks of the Piedmont; the consolidated sedimentary rocks of the Interior Low Plateau, the Appalachian Plateau, and the Valley and Ridge; and the generally unconsolidated rocks of the Coastal Plain. Figure 10 is a generalized geologic map of Alabama.

Igneous and Metamorphic Rocks -

The igneous and metamorphic rocks of the Alabama Piedmont are composed of schists, phyllites, gneisses, quartzites, marbles, gabbros and granites. These rocks are low in permeability except locally where ground water moves along open fractures. Recharge to these materials is through the weathered and decomposed rock. Well yields are small but adequate for domestic and small municipal and industrial uses. Most wells yield 0.6 l/s (10 gpm) or less but a few yield 3 l/s (50 gpm) or more. The marble yields up to 56 l/s (900 gpm) to wells.[11]

Sedimentary Rocks -

The rocks of the Interior Low Plateau, the Appalachian Plateau, and the Valley and Ridge consist of limestone, dolomite, chert, and sandstone. Individual well yields of more than 12.5 l/s (200 gpm) from the limestones and dolomites are common, and some yield more than 63 l/s (1,000 gpm). Yields tend to be erratic because of the irregular distribution pattern of the permeable cavernous zones within the limestones and dolomites. Wells in the sandstone aquifers yield from a few to about 15.6 l/s (250 gpm), and yields of 3 l/s (50 gpm) or more are common.[11]


TENNESSEE
FLORIDA
GULF OF MEXICO
0 20 40 60 Km
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COASTAL PLAIN ROCK AGE
PLEISTOCENE AND HOLOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
CONSOLIDATED ROCK TYPES
IGNEOUS AND METAMORPHIC
CARBONATE AND OTHER SEDIMENTARY

Figure 10. Generalized geologic map of Alabama.10)

Unconsolidated Rocks -

The unconsolidated rocks of the Coastal Plain consist of southward-dipping beds of sand and gravel, and of porous limestone interbedded with chalk, marl, and clay. The range in yields of wells in the area is from less than one l/s (less than 16 gpm) to over 63 l/s (1,000 gpm); yields of 31 l/s (500 gpm) are common.11) Commonly, the water is under artesian conditions. Table 5 lists the Coastal Plain stratigraphic units, their generalized lithology, and their water-bearing properties.

Florida

Florida lies entirely in the Coastal Plain physiographic province and ground-water region. The peninsular portion is a south-southeastward-trending, low, elongated dome of Coastal Plain strata, consisting mostly of limestone and dolomite. The Peninsular arch and the Ocala uplift are the principal structures. Figure 11 is a generalized geologic map of Florida.

There are four major developed aquifers in Florida; Figure 12 shows the areas of the state in which each constitutes the principal source of ground-water supplies. Table 6 lists the geologic units and their characteristics. The Floridan Aquifer, of middle Eocene to middle Miocene age, is the major source of ground water in the state. It crops out in few places, primarily in the northern part of the Panhandle, and recharge to it occurs principally in central Florida where the confining layer is breached by sinkholes and the aquifer is overlain by permeable sediments. Ground water moves radially from these recharge areas, a portion discharging to springs and streams, and the remainder discharging beyond the coastline as submarine springs. Artesian conditions occur where overlying deposits of impermeable materials confine the aquifer, and in some parts of the state flowing well conditions result when the confining units are penetrated. The Floridan Aquifer is at least 457 m (1,500 ft) thick in southern Florida.17) Well yields generally are at least 15.5 l/s (250 gpm) and some wells have produced as much as 1,250 l/s (20,000 gpm).15)

Another important water-bearing unit is the Biscayne aquifer in the southeastern part of the state. It is composed of rocks ranging in age from late Miocene through Pleistocene. The aquifer, under water-table conditions, is underlain by materials of very low permeability that inhibit upward movement of saline water. However, landward movement of salty ground water in coastal areas is a hazard when

Table 5. GEOLOGIC UNITS AND THEIR CHARACTERISTICS - ALABAMA COASTAL PLAIN[10-13]

System	Series		Stratigraphic units	Generalized lithology	Water-bearing properties
Quaternary	Pleistocene and Holocene		Alluvial and Terrace Deposits	Sand, gravel, clay, silt	Important aquifer in some areas
Tertiary	Pliocene and Pleistocene		Citronelle and younger deposits	Sand, fine to coarse, with gravel and clay lenses	Minor aquifer
	Miocene		Catahoula Sandstone & Paynes Hammock Sand	Clay, sandy clay, and beds of fine to coarse sand, sandstones, micaceous	Major aquifer
	Oligocene		Chickasawhay Limestone and Vicksburg Group	Limestone, sandy, dolomitic with sandy, silty clay and fine sand (interbedded)	Minor aquifer
	Eocene	Jackson Group	Yazoo Clay and Moodys Branch	Clay, sand, limestone and chalky marl	Generally leaky confining unit
		Claiborne Group	Gosport Sand, Lisbon and Tallahatta	Sand, fine to coarse, with clay lenses. Calcareous and glauconitic	Major aquifer
		Wilcox Group	Hatchetigbee	Sand, fine; clays glauconitic	Minor aquifer
			Tuscahoma Sand	Sand, clay and silt; laminated, micaceous, carbonaceous, glauconitic	Minor aquifer
			Nanafalia	Sand, sandstone, clay and claystone. Gravelly sand at base	Major aquifer
	Paleocene	Midway Group	Naheola	Sandy silt and silty clay with fine sand, glauconitic and lignitic. Some marl.	Minor aquifer
			Porters Creek Clay	Massive marine clay	Confining bed
			Clayton	Chalky marl and limestone with silt and sand layers	Major aquifer
Upper Cretaceous		Selma Group	Prairie Bluff Chalk	Brittle, sandy, chalk	Not an aquifer
			Ripley	Sand, sandstone, sandy limestone and clay—interbedded	Major aquifer
			Demopolis Chalk	Chalk and marl	Not an aquifer
			Mooreville Chalk	Chalky marl	Not an aquifer
			Eutaw	Massive to thin-bedded sand and clay, glauconitic	Major aquifer
			McShan	Alternating thin beds of sand and clay, glauconitic	Often considered part of Eutaw aquifer

Table 5 (Cont.) GEOLOGIC UNITS AND THEIR CHARACTERISTICS - ALABAMA COASTAL PLAIN[10-13]

System	Series	Stratigraphic units		Generalized lithology	Water-bearing properties
		Tuscaloosa Group	Gordo	Chiefly clay at top. Lower part chiefly sand and gravel	Major aquifer
			Coker	Upper part chiefly clay. Middle part alternating sand and clay. Lower part is gravelly sand	Major aquifer

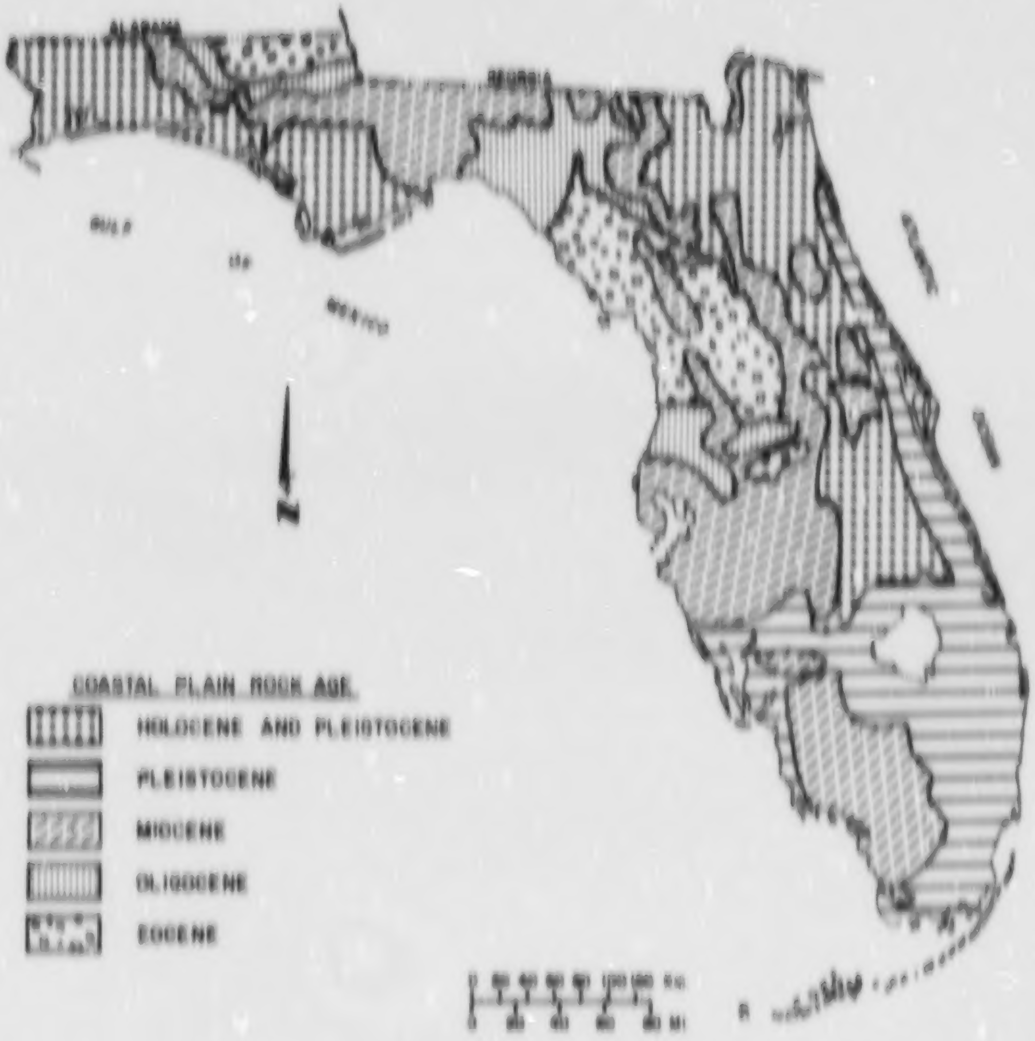
ALABAMA
GEORGIA
GULF
OF
MEXICO
ATLANTIC
OCEAN
N
COASTAL PLAIN ROCK AGE
HOLOCENE AND PLEISTOCENE
PLEISTOCENE
MIOCENE
OLIGOCENE
EOCENE
0 20 40 60 80 100 120 KM
0 20 40 60 80 MI

Figure 11. Generalized geologic map of Florida.14)

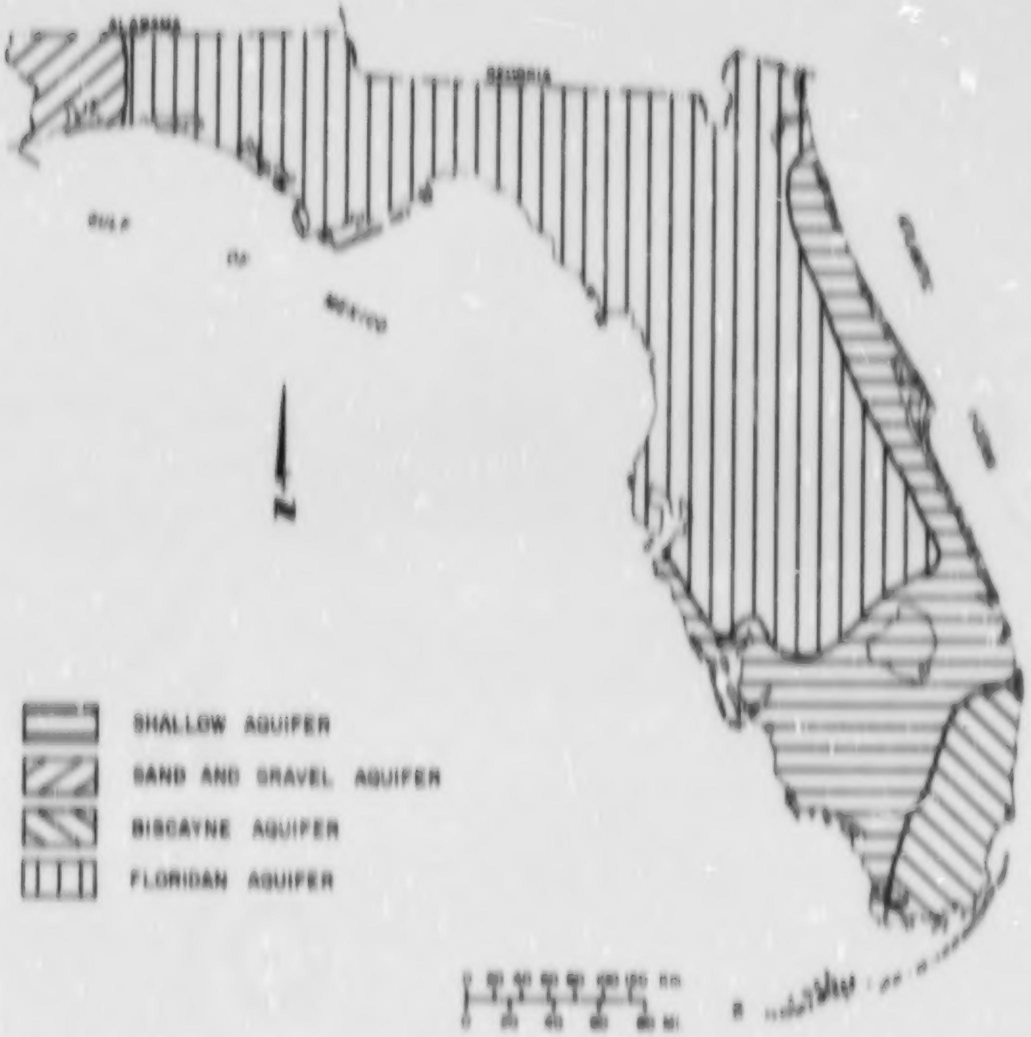
ALABAMA
GEORGIA
GULF
OF
MEXICO
N
SHALLOW AQUIFER
SAND AND GRAVEL AQUIFER
BISCAYNE AQUIFER
FLORIDAN AQUIFER
0 20 40 60 80 MI

Figure 12. Principal sources of potable ground water in Florida.$^{15,16)}$

Table 4. GEOLOGIC UNITS AND THEIR CHARACTERISTICS IN FLORIDA[7-41]

System	Series	Stratigraphic units	Hydrogeologic units	Generalized lithology	Water-bearing properties
Quaternary	Holocene	Lower marine and estuarine terrace deposits		Peat and muck	Relatively impermeable
		Lake Flirt Marl		Fossiliferous, calcareous marl	Relatively impermeable
	Pleistocene	Pamlico Sand	Shallow aquifer	Quartz sand, very fine to coarse	Yields water to sand-point wells
		High Terrace deposits		Quartz sand with interbedded clay and silt	Yields water to sand-point wells
		Miami Oolite	Biscayne Aquifer	Limestone, oolitic, with vertical solution holes	Fair to high permeability
		Anastasia Fm.	Shallow aquifer	Coquina, sand, calcareous sandstone, sandy limestone and shell marl	Fair to high permeability
		Key Largo Limestone		Coralline reef rock, hard and dense to soft and cavernous	High permeability
		Fort Thompson Fm.		Marl, limestone and sandstone	High permeability
		Caloosahatchee Marl		Shells, sands and marl	Generally low permeability and quality
	Plio-Pleistocene	Citronelle	Sand & gravel Aquifer	Quartz sand and gravel with clay beds	Very permeable
Tertiary	Miocene	Tamiami Fm.	Shallow aquifer	Limestone, sand and marl	Upper portion very permeable
		Jackson Bluff Fm.		Clayey sands and shell marl	Low permeability except locally
		Fort Preston Fm.		Gray-white thinly laminated sands	Low permeability except locally
		Bone Valley Fm.		Phosphatic boulders and pebbles and sandy clay	Low permeability except locally
		Alachua Fm.		Interbedded, clay, marl, sandy clay	Low permeability except locally
		Hawthorn Fm.	Floridan Aquifer	Interbedded sand, clay and limestone and sandy phosphatic limestone and marl	Lower part has moderate to good permeability
	Tampa Group	St. Marks Fm.		Sandy, chalky limestone	Moderate permeability
		Chattahoochee Fm.		Sandy, chalky limestone	Moderate permeability

Table 4 (cont.) GEOLOGIC UNITS AND THEIR CHARACTERISTICS IN FLORIDA[illegible]

System	Series	Stratigraphic units	Hydrogeologic units	Generalized lithology	Water-bearing properties
Tertiary (cont.)	Oligocene	Suwannee Limestone	Floridan Aquifer	Limestone	Moderate permeability
	Eocene	Ocala Group: Crystal River Fm.		High-calcium limestone	Very permeable in some areas.
		Ocala Group: Williston Fm.		Fragmental limestone	Principal components of the Floridan Aquifer
		Ocala Group: Inglis Fm.		Fragmental limestone and finely crystalline dolomite	
		Avon Park Limestone		Chalky limestone and dolomite with gypsum and chert	Very permeable to poorly permeable
		Lake City Limestone		Dolomite and chalky limestone	Locally very permeable
		Oldsmar Limestone		Limestone with chert and gypsum	Locally permeable generally saline
	Paleocene	Cedar Keys Limestone		Limestone	Generally saline

natural ground-water gradients are reduced by pumping, sewering, or construction of drainage systems. Recharge is derived from local rainfall and from canals that carry water from the inland conservation areas. The aquifer ranges in thickness from a thin veneer in the western portion to 30 m (125 ft) in the Miami area.[17] It yields as much as 95 l/s (1,500 gpm) to wells.[16]

The major aquifer in the western part of the Panhandle is the Sand-and-Gravel aquifer, a wedge-shaped deposit probably of deltaic origin. This water-table aquifer is composed of sediments ranging in age from Miocene to Pleistocene, and is thickest, as much as 213 m (700 ft), along the coast. Yields of from 3.2 to 126 l/s (50 to 2,000 gpm) are reported.[16]

Most of Florida is underlain by a water-bearing unit known as the Shallow aquifer. In most areas it is not developed extensively because a better supply is available from other aquifers. The principal areas of use of this aquifer are along the east coast and in a wide belt extending across southern Florida in the vicinity of Lake Okeechobee. The rocks composing it range in age from Miocene to Recent, with the younger beds to the north. Recharge is derived from local rainfall. The thickness of the aquifer in places can exceed 122 m (400 ft), with reported yields of up to 126 l/s (2,000 gpm).[15,18,19]

Georgia

Segments of five physiographic provinces are found in Georgia: the Coastal Plain, the Piedmont, the Blue Ridge, the Valley and Ridge, and the Appalachian Plateau (Figure 5). The state is divided into two ground-water regions: the Coastal Plain and the Unglaciated Appalachian (Figure 6). The southeastern three-fifths of the state is in the Coastal Plain.

The Unglaciated Appalachian region contains consolidated sedimentary, igneous, and metamorphic rocks. The sedimentary rocks are located in the Valley and Ridge and the Appalachian Plateau physiographic provinces and are generally referred to as the Paleozoic aquifer. The igneous and metamorphic rocks are situated in the Piedmont-Blue Ridge area.

The Coastal Plain region is underlain by generally unconsolidated to partially consolidated sedimentary rocks. This region is sub-divided into the Upper Coastal Plain and the

Lower Coastal Plain on the basis of geologic age. Figure 13 is a generalised geologic map of Georgia.

Paleozoic Aquifer -

Limestone, dolomite, scndstone, and shale are the principal consolidated sedimentary rocks underlying the area. The major aquifers are the limestones and dolomites, which usually yield to wells from less than three to more than 63 l/s (less than 50 to more than 1,000 gpm),[24] but yields as high as 200 l/s (3,200 gpm) to wells are reported.[11] The sandstones and shales generally yield to wells from 0.06 to not more than 1.9 l/s (one to not more than 30 gpm).[25]

Piedmont-Blue Ridge Aquifers -

The igneous and metamorphic rocks consist of marble, quartzite, slate, schist, gneiss, and granite. Ground-water movement in these rocks is along fractures or through weathered zones. Well yields are seldom in excess of a few l/s (few tens of gpm), but under some localised conditions are in excess of 12.5 l/s (200 gpm).[11]

Coastal Plain Aquifers -

The Coastal Plain can be divided into two areas that overlap slightly: the upper and lower Coastal Plains. In the updip area, or upper Coastal Plain, ground water is obtained from sands of Cretaceous age and from limestone and sand of early Tertiary age. The downdip area, or lower Coastal Plain, contains a thickening sequence of Tertiary limestone which is a most prolific aquifer. Table 7 lists the geologic units and their water-bearing properties.

The upper Coastal Plain, bounded on the north by the Piedmont, is underlain by alternating clays and sands of Cretaceous age. Well yields of up to 125 l/s (2,000 gpm) are reported.[11] In southwestern Georgia the Paleocene-Eocene limestone-sand aquifer supplies water to multiple-screened wells having yields in excess of 31 l/s (500 gpm).[28]

The major water-bearing unit in the lower Coastal Plain is the principal artesian aquifer. It consists of an extensive, permeable, limestone aquifer of Tertiary age overlain by a thick sequence of relatively impermeable Miocene deposits. This hydrologic unit correlates with the Floridan Aquifer. The major area of use is along the Atlantic coast of Georgia where tens of thousands of cu m/d (tens of mgd) are withdrawn at the various population centers.[11]

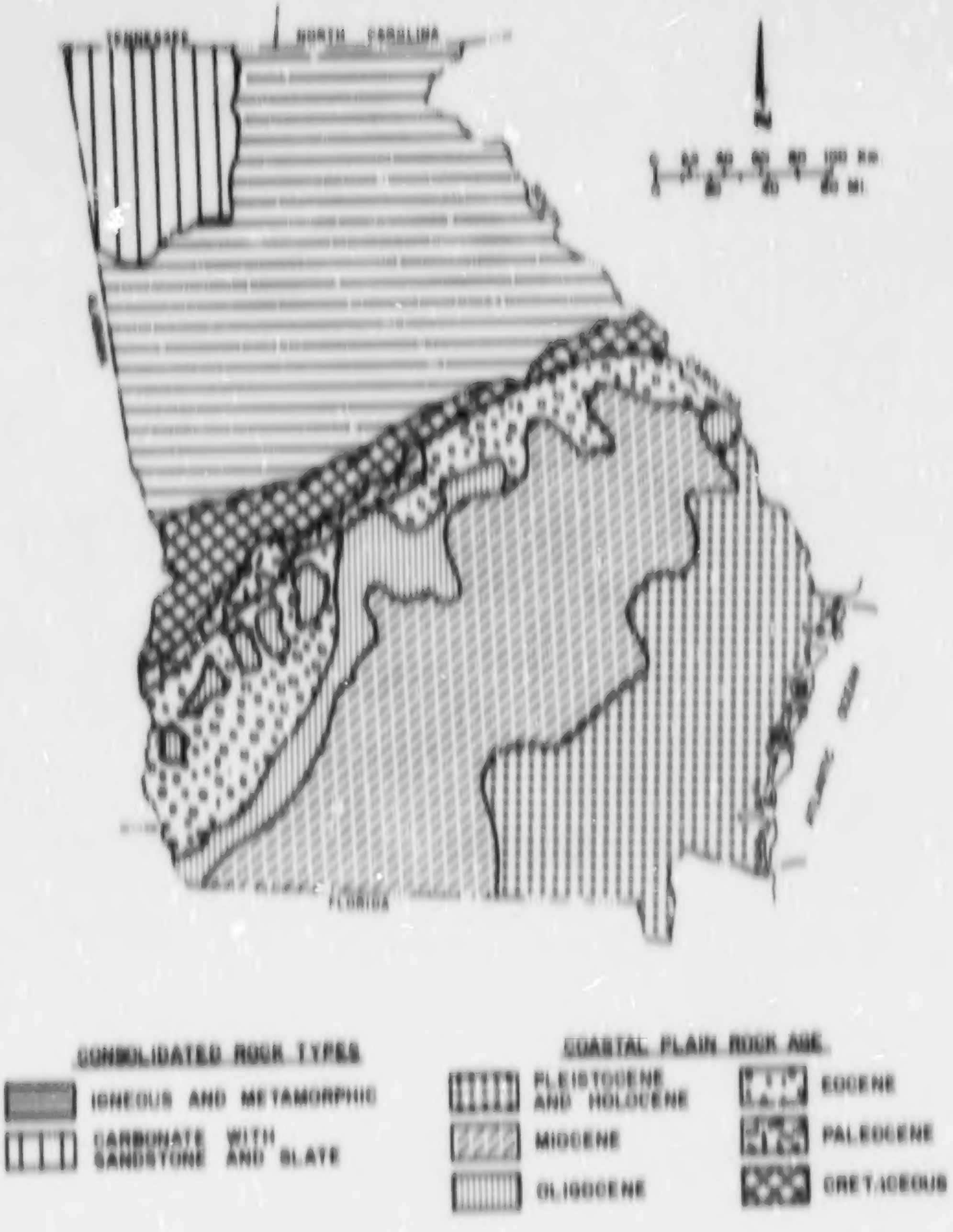
TENNESSEE
NORTH CAROLINA
0 20 40 60 80 100 KM
0 20 40 60 MI
FLORIDA
CONSOLIDATED ROCK TYPES
IGNEOUS AND METAMORPHIC
CARBONATE WITH SANDSTONE AND SLATE
COASTAL PLAIN ROCK AGE
PLEISTOCENE AND HOLOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS

Figure 13. Generalized geologic map of Georgia.23)

Table 7. GEOLOGIC UNITS AND THEIR CHARACTERISTICS - GEORGIA COASTAL PLAIN[illegible]

System	Series	Stratigraphic units	Generalized lithology	Water-bearing properties Yield range in l/s (gpm)
Quaternary	Holocene	Stream and shore deposits	Sand and gravel, with silt and clay	Contain appreciable water—not used due to flooding
	Pleistocene	Terrace deposits	Sand and gravel, with silt, clay and boulders	Often too high above streams to be recharged
Tertiary	Plio-Pleistocene	Undifferentiated (Citronelle?)	Sand and gravel	Dry because of drainage or not used due to flooding
	Miocene	Hawthorn	Clay; clayey sand; calcareous sandstone; phosphatic sandy limestone; marl	Relatively impermeable serves as a confining unit 0-1 (0-20)
		Tampa Limestone	Limestone, sandy, phosphatic	Yields up to 12.5 (200)
	Oligocene Undifferentiated	Suwannee Limestone	Limestone, dense to soft and chalky, with chert and gypsum	Major aquifer 1.25-131 (20-2100)
	Eocene	Jackson Group (includes Ocala Limestone and Barnwell Form.)	Limestone, fossiliferous or dense and dolomitic; Sand, marl and clay	Major aquifer Yields 2 to 250 (30 - 4,000)
		Claiborne Group (Gosport Sand, McBean, Lisbon and Tallahatta)	Glauconitic limestone and sand, pyritic and dolomitic some gypsum and chert	Yields as high as 19-75 (300-1,200) Some contain [illegible] [illegible]
	Paleocene	Wilcox Group (includes Tuscahoma Sand and Nanafalia)	Alternating micaceous lignitic clay and sand with some glauconitic limestone	Tuscahoma Sand will yield up to 31 (500) in area of limestone-sand aquifer
		Midway Group (Clayton Form.)	Glauconitic limestone with minor clay and sand	Yields 15.5 - 106 (250-1,700) Major aquifer
Cretaceous	Upper Cretaceous	Providence Ripley Cusseta Blufftown Eutaw Tuscaloosa	Alternating green, red and purple micaceous clays and fine to coarse sand with sandy limestone	Yields 3 - 75 (50-1,200) may be high in iron and in [illegible] [illegible]

Mississippi

There are two basic rock types in Mississippi: the consolidated sedimentary rocks of the extreme northeast corner of the state (a part of the Unglaciated Central ground-water region) and the unconsolidated to semi-consolidated sediments of the Coastal Plain (Figure 6). The consolidated rocks consist of sandstone, limestone, and weathered chert of Paleozoic age. The sediments of the Coastal Plain are of Cretaceous, Tertiary and Quaternary age, and consist of clay, silt, sand, gravel, marl, chalk, and limestone. These form a wedge-shaped mass which in the northern part of the state dips westerly toward the axis of the Mississippi Structural Trough; the trough coincides roughly with the present course of the Mississippi River. In southern Mississippi the sediments dip southward toward the Gulf Coast Geosyncline. Figure 14 is a generalized geologic map of Mississippi.

Consolidated Rocks -

The sandstone, limestone, and weathered chert of Paleozoic age occur in a very small area in the northeast. The water quality is generally good and well yields may be as high as 50 l/s (800 gpm). Electric logs of borings for oil and gas in this area indicate that undeveloped portions of this aquifer are available for use in several counties.32)

Unconsolidated and Semi-Consolidated Sediments -

The unconsolidated and semi-consolidated sediments of the Coastal Plain cover almost the entire state. Table 8 lists the stratigraphic units, their generalized lithology and thickness, and their water-bearing properties. Aquifers capable of yielding 125 l/s (2,000 gpm) or more to wells are found in almost three-fourths of the counties of the state.31) The various aquifers are used as sources of water in their outcrop areas and downdip to a point where the overlying shallow aquifers are more economical to develop, or to a point where the water quality renders the water unuseable.

North Carolina

North Carolina lies principally in the Coastal Plain and Piedmont physiographic provinces, with a small segment along the western edge lying in the Blue Ridge physiographic province (Figure 5). The state is situated in the Unglaciated Appalachian and Coastal Plain ground-water regions. The Unglaciated Appalachian Region is underlain by igneous, metamorphic and consolidated sedimentary rocks. The Coastal

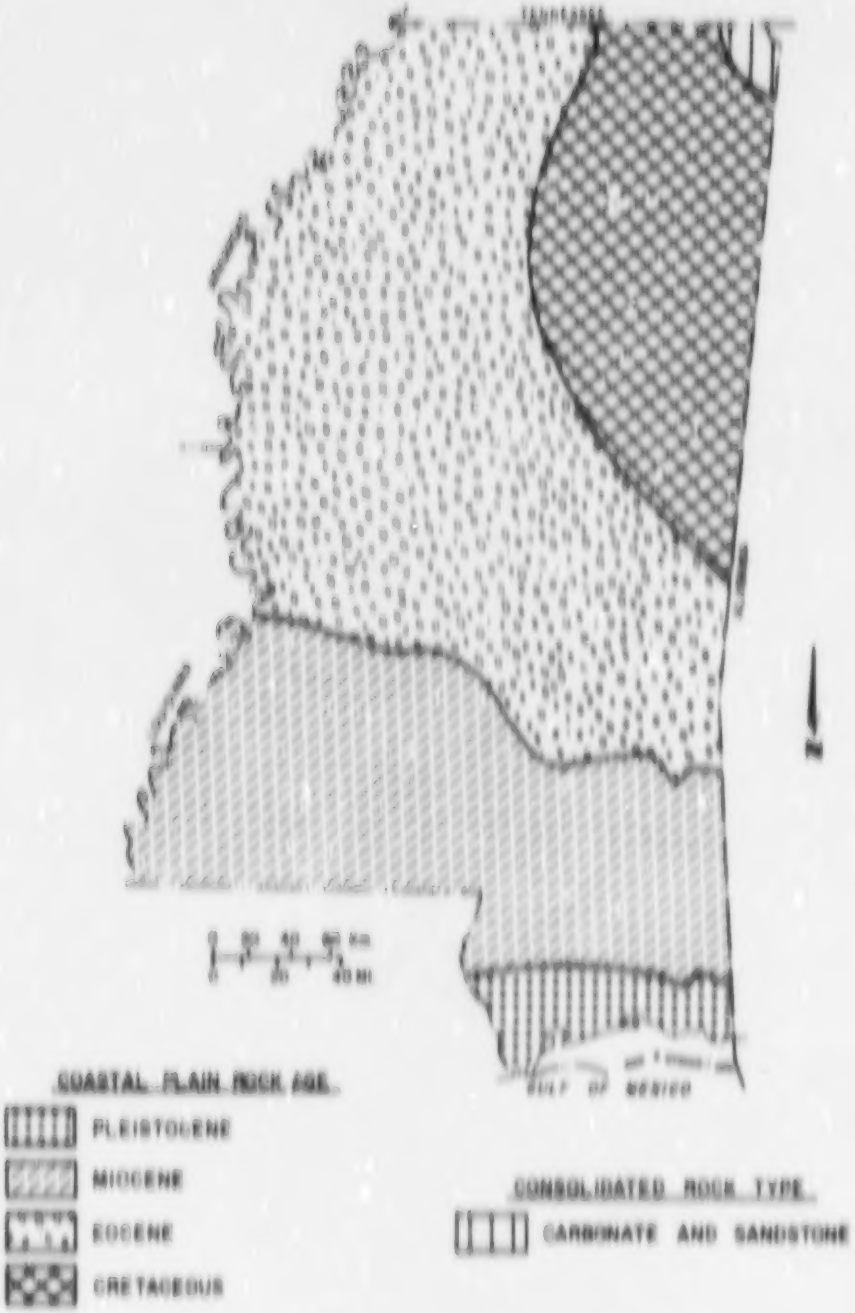
TENNESSEE
0 20 40 60 KM
0 20 40 MI
GULF OF MEXICO
N
COASTAL PLAIN ROCK AGE
PLEISTOCENE
MIOCENE
EOCENE
CRETACEOUS
CONSOLIDATED ROCK TYPE
CARBONATE AND SANDSTONE

Figure 14. Generalized geologic map of Mississippi.[30,31]

Table 8. GEOLOGIC UNITS AND THEIR CHARACTERISTICS IN MISSISSIPPI.[33-40]

System	Series		Stratigraphic units	Generalized lithology and thickness meters (feet)	Water-bearing properties Yield range and average in l/s (gpm)
Quaternary	Holocene		Alluvium	Silt, clay, coarse sands and gravels, 0-61 (0-200)	Major aquifer 2-225 (30-3,600) 79 (1,250)
	Pleistocene		Loess	Silt (windblown) 0-33 (0-100)	Not an aquifer
			Terrace Deposits	Sand and gravel w/clay, 0-31 (0-100)	Locally important
			Citronelle	Sand, gravel, silt and clay 0-31 (0-100)	Major aquifer 0.6-35 (10-550) 17 (268)
Tertiary	Pliocene		Graham Ferry	Sands and gravels separated by clays. 0-61 (0-200)	Major aquifer 4-94 (63-1,500) 27 (441)
	Miocene		Pascagoula Hattiesburg Catahoula	Sands and gravels separated by clays Pascagoula 0-305 (0-1,000) Hattiesburg 0-122 (0-400) Catahoula 0-275 (0-900)	Major aquifer often hard to separate these units 1.1-90 (2-1,400) 18 (285)
	Oligocene		Vicksburg	Sand, marl, and limestone 0-49 (0-160)	Generally not an aquifer
			Forest Hill	Sand 0-76 (0-250)	Minor aquifer
	Eocene		Yazoo Clay	Clay 0-160 (0-525)	Confining bed
			Moodys Branch	Marl 3-14 (10-45)	Not an aquifer
		Claiborne Group	Cockfield	Clay w/lignitic beds and coarse sands 0-168 (0-550)	Major aquifer 1.26-97 (2-1,550) 27 (425)
			Cook Mountain	Sand and limestone 0-76 (0-250)	Not an aquifer
			Kosciusko (Sparta Sand)	Sands and clays 0-244 (0-800)	Major aquifer 1.6-200 (25-3,200) 31 (502)
			Zilpha	Carbonaceous shale and clay w/lenses of silt and sand 0-153 (0-500)	Not an aquifer
			Winona	Sand, fossiliferous, glauconitic, fine to coarse 0-15 (0-50)	Minor aquifer
			Tallahatta (Neshoba and Meridian Sand)	Sand, micaceous, fine to coarse w/clay, shale, claystone, siltstone, and sandstone 0-198 (0-650)	Major aquifer 0.2-86 (3-1,375) 26 (417)

Table 8 (cont'd). GEOLOGIC UNITS AND THEIR CHARACTERISTICS IN MISSISSIPPI[11-40]

System	Series	Stratigraphic units	Generalized lithology and thickness metres (feet)	Water-bearing properties Yield range and average in l/s (gpm)
Tertiary	Eocene	Wilcox Group	Sand, shale, silt and clay 0-1066 (0-3,500)	Major aquifer 0.6-136 (10-2,162) 26 (412)
	Paleocene	Midway Group	Sand, clay, limestone and marl 0-207 (0-680)	Not an aquifer
Cretaceous	Gulf	Prairie Bluff Chalk and Owl Creek	Chalk and marl 12 (40)	Not an aquifer
		Ripley	Sand, clay, limestone and chalk, 0-137 (0-450)	Major aquifer 1-16 (15-250) 6 (100)
		Demopolis Chalk	Chalk, 0-153 (0-500)	Not an aquifer
		Coffee Sand	Sand, sandy clay and calcareous sandstone 0-76 (0-250)	Minor aquifer 10-22 (160-350) 17 (274)
		Mooreville Chalk	Chalk, 0-61 (0-200)	Not an aquifer
		Eutaw	Sand, glauconitic, fine, silty 0-61 (0-200)	Major aquifer 1.7-51 (27-808) 21 (340)
		Tuscaloosa	Sand, coarse and gravel, rounded w/clay, 0-458 (0-1,500)	Major aquifer 1.6-63 (25-1,000), 16 (250)
Lower Cretaceous	Comanche	Undifferentiated	Sand, silt, gravel, chalk and limestone, 0-305 (0-1,000)	Potential aquifer (untapped)
Pennsylvanian, Mississippian, and Devonian		Undifferentiated carbonates and sandstone	Sandstone, limestone and weathered chert, 305-plus (1,000-plus)	Minor aquifer (locally important) 6-50 (100-800) 28 (445)

Plain, situated in the eastern half of the state, is underlain by beds of sand, clay, marl, and limestone. These deposits form a thickening wedge of sediments to the southeast. Figure 15 is a generalized geologic map of North Carolina.

Consolidated Rocks -

The igneous and metamorphic rocks are very complex in character and occurrence, but may be considered to be of two general types: massive granite-like rocks, and bedded slate-like rocks. Ground water is stored in the weathered zone and also in the rock itself where fracturing has taken place. Water moves through these openings much less readily than through the pores of the sediments of the Coastal Plain, and well yields of less than 1.9 l/s (30 gpm) are common. Statistics on municipal and industrial wells in the region show that 60 percent yield at least 1.1 l/s (18 gpm), 40 percent yield at least 2.1 l/s (33 gpm), and 20 percent yield at least 3.4 l/s (54 gpm).[42]

Two northeast-trending belts of consolidated sedimentary rocks of Triassic age are situated in the region. These rocks, chiefly sandstones and shales, are tightly cemented and dense. Water occurs chiefly in joints, and yields of wells are somewhat comparable to those of the surrounding igneous and metamorphic rocks. Small domestic ground-water supplies are commonly available, but few wells yield as much as 4.7 l/s (75 gpm).

Unconsolidated Rocks -

The Coastal Plain occupies the eastern portion of North Carolina. The plain is characterized by a gentle rise from sea level at the coast to an elevation of more than 91.4 m (300 ft) along the western inner margin. Deposits of sand, clay, marl, and limestone of Cretaceous, Tertiary, and Quaternary age dip seaward. The geologic materials are unconsolidated except for some limestones. Table 9 lists the geologic units of the Coastal Plain and their characteristics.

The Coastal Plain is primarily a rather large and complex artesian system. The alternating layers of permeable and relatively impermeable beds and their gentle seaward slopes produce artesian conditions. The aquifers, which commonly are medium- to coarse-grained sands or limestones, and the intervening impermeable beds, commonly clays or shales, vary greatly in thickness and areal extent. Some geologic formations contain several aquifers and several impermeable

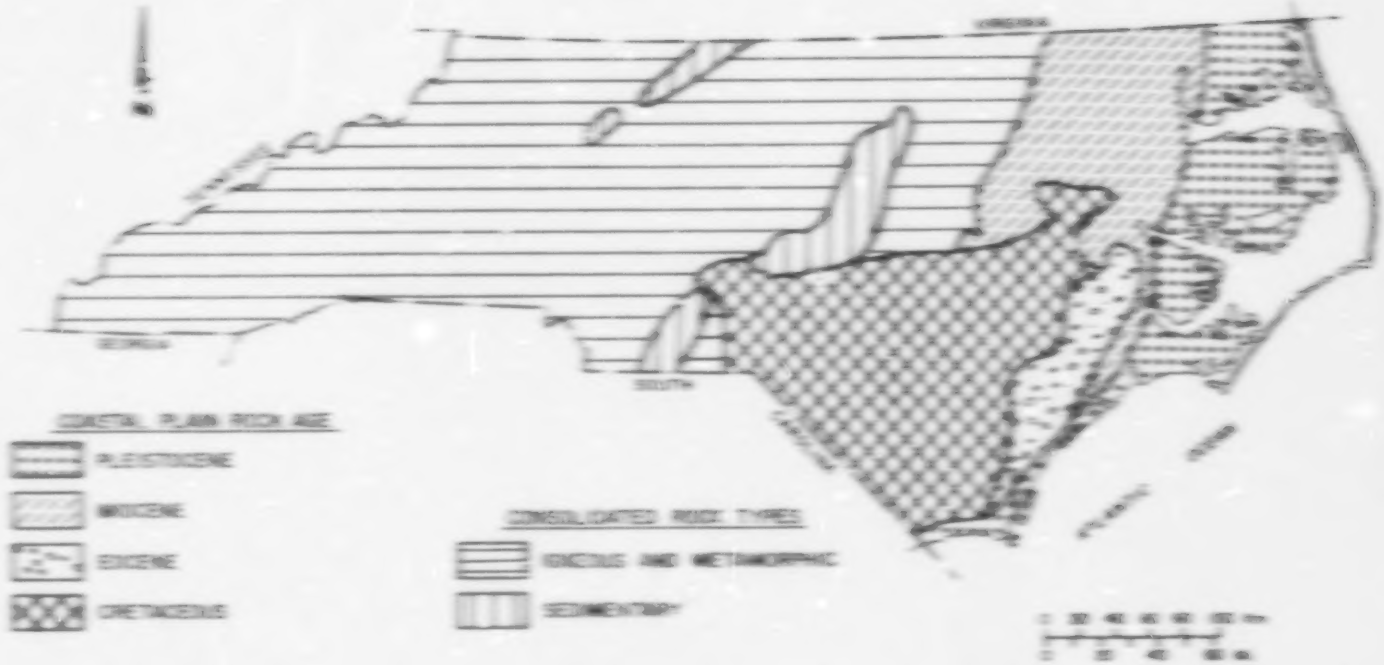
N
VIRGINIA
GEORGIA
SOUTH CAROLINA
ATLANTIC OCEAN
COASTAL PLAIN ROCK AGE
PLEISTOCENE
MIOCENE
EOCENE
CRETACEOUS
CONSOLIDATED ROCK TYPES
IGNEOUS AND METAMORPHIC
SEDIMENTARY

Figure 15. Generalized geologic map of North Carolina.[41]

Table 5. GEOLOGIC UNITS AND THEIR CHARACTERISTICS - NORTH CAROLINA COASTAL PLAIN[illegible]

System	Series	Stratigraphic units	Generalized lithology	Water-bearing properties Yield range in l/s (gpm)
	Holocene	Recent	Sands, clays and gravels	Domestic wells
Quaternary	Pleistocene	Columbia Group	Sandy clay, clayey sand and some clean sand and gravel	Source of major portion of domestic supplies 0.3-2.5 (5-40)
Tertiary	Pliocene	Croatan Sand	Sand, fossiliferous	Minor aquifer (maximum of 19 (300)
		Waccamaw	Shell marl and calcareous sands and clays	Low yield to domestic wells
	Miocene	Duplin Marl	Calcareous sands, clays, marls	Low yield to domestic wells
		Yorktown	Interbedded sands and clays with some sandy limestone layers	Yields 3-41 l/s (50-650)
		Trent Marl	Limestone, calcareous sandstone, sand and marls	Yields 12.5-63 (200-1,000)
	Eocene	Castle Hayne Limestone	Limestone, sandy limestone, calcareous sandstone, calcareous sands, and marls	Major aquifer 3-63 (50-1,000)
	Paleocene	Beaufort	Glauconitic sands	Minor aquifer
Cretaceous	Upper Cretaceous	Pee Dee	Interbedded sands, clays and marls glauconitic	Major aquifer 3-113 (50-1,800)
		Black Creek	Thinly laminated sands and clays pyritic, lignitic, micaceous Upper portion is a calcareous greensand and marine clay	Major aquifer 3-56 (50-900)
		Tuscaloosa	Arkosic sand, clay and gravel	Major aquifer 2-63 (25-1,000)
	Lower Cretaceous	Patuxent (?)	Sand, silt, clay	Generally contains saline water

layers, whereas other formations compose only a part of an aquifer. Many aquifers are separated by beds that are lenticular and not altogether impermeable. Considerable vertical leakage takes place where there is a difference in head between such aquifers.

Two types of artesian systems generally characterize the region: the Cretaceous sand aquifer and the Tertiary limestone aquifer. The Cretaceous sand aquifer is developed for water supply over a broad area. It consists of several sand beds that are confined beneath intervening beds of clay. Some industrial and municipal wells utilize multiple-screened wells, and water is withdrawn from several sand aquifers. Many of these wells yield more than 31.5 l/s (500 gpm) with less than 30.5 m (100 ft) of drawdown. Other wells, commonly of the open-end tubular type, obtain high yields from the Tertiary limestone aquifers.(43)

Throughout the Coastal Plain, the water-table aquifer is used widely for individual domestic water supplies. However, there is no significant use of this aquifer for industrial and municipal water supply. The water-table aquifer is composed principally of sands varying widely in character and age from place to place. It is commonly less than 9.2 m (30 ft) thick, and is underlain by clay that represents the top confining bed of the artesian system.

South Carolina

South Carolina is located in parts of three physiographic provinces (Figure 5). The southeastern portion of the state is in the Coastal Plain, and except for a small area of the Blue Ridge province in the extreme northwest, the remainder is in the Piedmont province. The area also lies in two ground-water regions: the Coastal Plain and the Unglaciated Appalachians (Figure 6).

The Blue Ridge portion of the Unglaciated Appalachians contains mainly crystalline and consolidated sedimentary rocks in which ground water occurs in fractures or the weathered zone. The Piedmont is underlain by folded metamorphic rocks intruded by bodies of igneous rocks. The Coastal Plain ground-water region is composed of generally unconsolidated to partially consolidated sedimentary rocks. Figure 16 is a generalized geologic map of South Carolina.

Piedmont-Blue Ridge Aquifers -

The rocks of the Piedmont-Blue Ridge physiographic region consist of granite, schist, gneiss, slate, and phyllite.

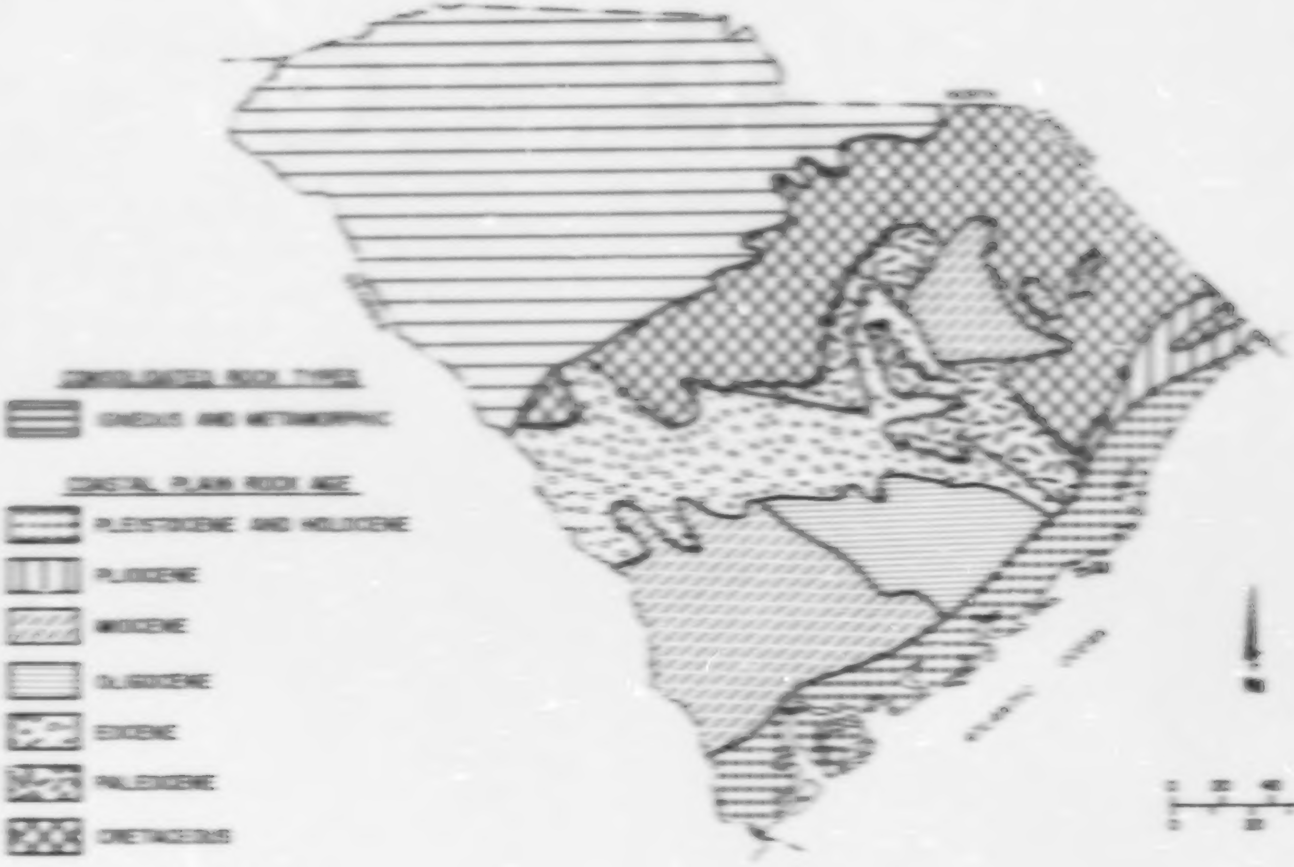
CONSOLIDATED ROCK TYPES
IGNEOUS AND METAMORPHIC
COASTAL PLAIN ROCK AGE
PLEISTOCENE AND HOLOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
ATLANTIC OCEAN
N
0 20 40 60 Km
0 20 40 Mi

Figure 16. Generalized geologic map of South Carolina.41)

Most wells will yield less than 3 l/s (50 gpm), but a few yield as much as 19 l/s (300 gpm).[11] The ground water is stored in open fractures or within pores of the residuum. Granites and schists usually have the highest yields.

Coastal Plain Aquifers -

The unconsolidated rocks of the South Carolina Coastal Plain consist of a thickening sequence of southeastward dipping beds of sand, gravel, clay, limestone and marl. The thickness of these sediments probably exceeds 914 m (3,000 ft) near the Atlantic coastline.[11] Table 10 lists the Coastal Plain stratigraphic units, their generalized lithology, and their water-bearing properties.

In the extreme south of South Carolina, the sedimentary rocks lie in a shallow basin centered at Savannah, Georgia. The major limestone aquifer in this area is the northernmost extension of the Ocala Limestone, a part of the "principal artesian aquifer" of Georgia and the Floridan aquifer of Florida. Other major aquifers are situated and developed in the Coastal Plain. The Tuscaloosa Formation underlies essentially the entire Coastal Plain. The Peedee and Black Creek Formations, which act as a single aquifer, are located throughout the central and eastern part of the lower Coastal Plain. The Black Mingo Formation is a major aquifer in the central coastal area. The Santee Limestone is generally utilized from the central coastal area to some 97 km (60 mi) or more inland.

Virginia

Ground-water use in Virginia is presently small compared with use of surface water, but ground water is an important source of supply both locally and regionally. The ground-water reservoir consists of a variety of aquifers composed of both consolidated and unconsolidated deposits. Figure 17 is a generalized geologic map of Virginia. Portions of the state lie in five different physiographic provinces (Figure 5).

Consolidated Rocks -

From west to east, the consolidated rocks consist of gently to intensely folded sedimentary rocks. Of the three principal types of rocks, the carbonate rocks occur beneath major lowlands such as the Shenandoah Valley, where they form the most productive aquifers. Yields commonly are as much as 19 l/s (300 gpm). The other rock types, sandstone and shale, generally underlie ridges or upland areas and yield sufficient water only for rural and domestic supplies.

Table [illegible]. GEOLOGIC UNITS AND THEIR CHARACTERISTICS - SOUTH CAROLINA COASTAL PLAIN[illegible]

System	Series		Stratigraphic units	Generalized lithology	Water-bearing properties Yield range in l/s (gpm)
Quaternary	Holocene or Pleistocene		Surficial Deposits	Clayey, quartzose and arkosic sand and gravel	Minor aquifers generally above water-table; often high iron, nitrate and sulfate; soft.
Tertiary	Pliocene		Unnamed Unit Citronelle (?) equivalent	Silt, sand and gravel with silty clay	
	Miocene		Duplin	Sandy, fossiliferous clay or marl with interbedded sand	Minor aquifer
			Hawthorn	Compact sandy clay with gravel and limonite nodules - phosphatic	Relatively impermeable confining bed
	Oligocene		Cooper Marl	Foraminiferal marl with sand lenses	Confining bed
	Eocene	Jackson	Barnwell	Sands interbedded with clays	Low yields
			Ocala Limestone	Lower part is granular calcitized limestone. Upper part crystalline fossiliferous limestone	Major aquifer in southeastern part of State [illegible]
		Claiborne	McBean	Loose sand interbedded with clays and grading into calcareous clays and limestones in direction of Santee Limestone	Yields 3-25 (50-400) Water is acidic and high in iron
			Santee Limestone	Highly fossiliferous limestone cherty, glauconitic, dolomitic	Yields 3-44 (50-700)
			Warley Hill	Sandy glauconitic clay, sand and limestone	Minor aquifer
			Congaree	Sand, interbedded with silty clays and hard siltstone and sandstone	Yields 3-25 (50-400)
		Wilcox	Black Mingo	Fine sand and sugary sandstone or bioclastic limestone with fullers earth and pyritiferous, lignitic shales	Minor aquifer acidic waters high in iron
	Paleocene		Unnamed unit	——	——

Table 10 (cont). GEOLOGIC UNITS AND THEIR CHARACTERISTICS - SOUTH CAROLINA COASTAL PLAIN[50, 51, 52]

System	Series	Stratigraphic units	Generalized lithology	Water-bearing properties Yield range in l/s (gpm)
Cretaceous	Upper Cretaceous	Peedee	Glauconitic, quartz sand and interbedded lenses of sandy marl or limestone and thick dark clay	Yields of 6-75 (90-1,200)
		Black Creek	Coarse-grain, glauconitic, phosphatic quartz sand interbedded with black lignitic, pyritic clay	Similar yield as Peedee Formation but high in iron and sulfate.
		Ellenton	Similar to the Black Creek Formation, but the sands are coarser and contain selenite	
		Tuscaloosa	Quartzitic and arkosic, micaceous medium to coarse sand and gravel interbedded with clay. Clays separate major unit into various aquifers	Most important aquifer in State, very low in dissolved solids, low pH, soft, with some high iron and sulfate. Yields up to 125 (2,000)

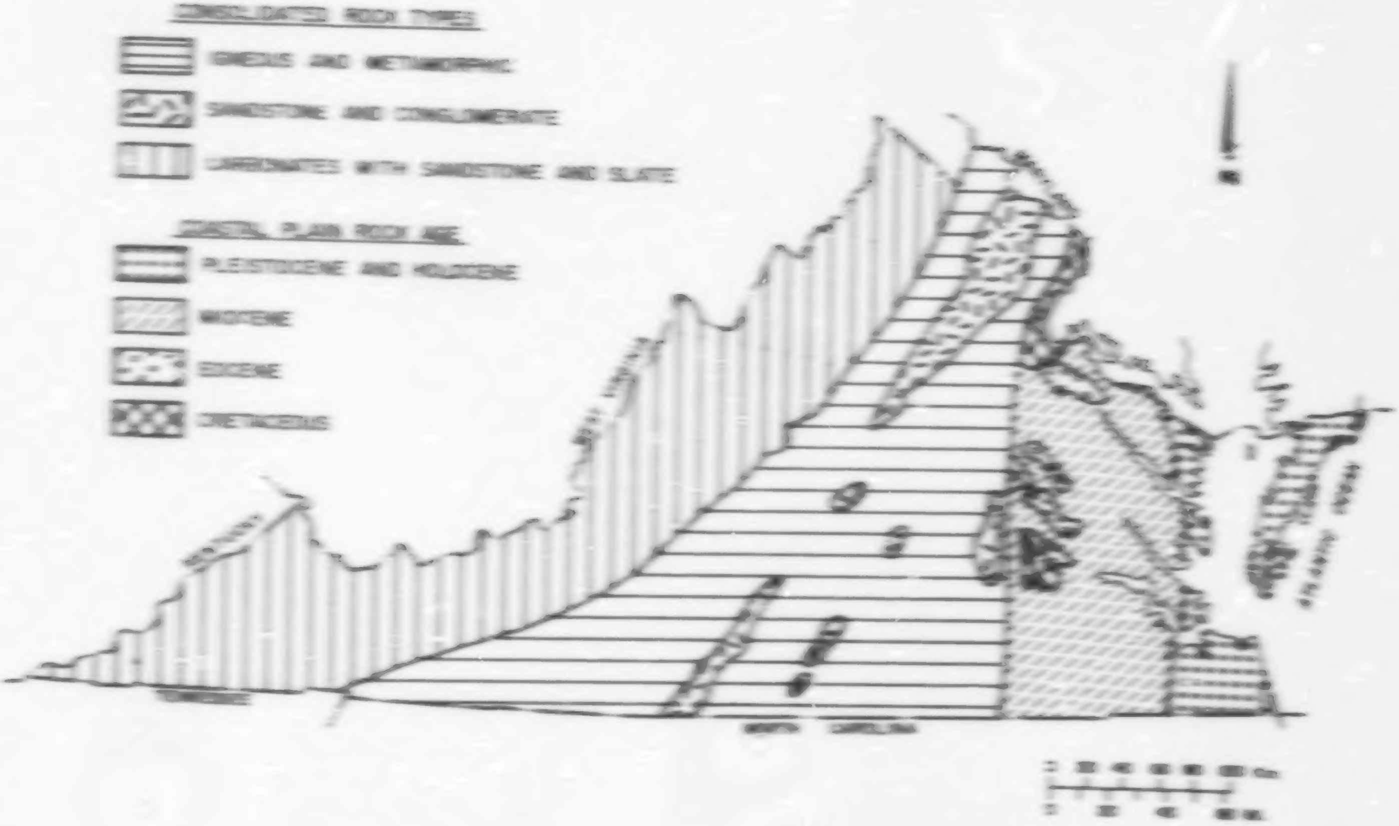
CONSOLIDATED ROCK TYPES
IGNEOUS AND METAMORPHIC
SANDSTONE AND CONGLOMERATE
CARBONATES WITH SANDSTONE AND SLATE
COASTAL PLAIN ROCK AGE
PLEISTOCENE AND HOLOCENE
MIOCENE
EOCENE
CRETACEOUS
WEST VIRGINIA
KENTUCKY
TENNESSEE
NORTH CAROLINA
ATLANTIC OCEAN
N
0 20 40 60 80 100 Km
0 20 40 60 Mi

Figure 17. Generalized geologic map of Virginia.41)

in the central half of the state, crystalline rocks such as granite and diorite, and metamorphic rocks such as schist, gneiss, phyllite, slate, and quartzite yield small quantities of water for domestic and rural use. Residual weathered bedrock materials, which range from about 6 to 30 m (20 to 100 ft) in thickness, in places yield as much or more water to wells than the underlying unweathered bedrock.[11]

Local bodies of sedimentary rocks of Triassic age occur in elongated downfaulted basins in the central area. Beds of sandstone and conglomerate in these basins comprise fair to moderately good aquifers with reported yields of some wells being as high as 38 l/s (600 gpm).[11] Less permeable shale and diabase in these basins yield quantities of water generally sufficient only for domestic supplies. Table 11 lists the lithologic and water-bearing properties of the consolidated rocks in Virginia.

Unconsolidated Deposits -

These deposits of sand, gravel, and clay occur in two geologic settings. The first, and least important, occurrence is in the form of discontinuous deposits in stream channels and as terrace deposits on the bedrock surface. These deposits, mainly of Pleistocene and Holocene age, commonly are hydraulically connected to streams and yield moderate quantities of water locally to dug and drilled wells.

The principal body of unconsolidated deposits is a wedge of Coastal Plain sediments which thickens from a feather edge at the Fall Line at the eastern boundary of the Piedmont Province to probably more than 900 m (3,000 ft) at the shoreline.[11] The deposits, composed of beds and lenses of sand, gravel, and clay of Cretaceous through Holocene ages, are highly productive and contain water in several aquifers under confined and unconfined conditions. The principal aquifer is in the Patuxent Formation. Well yields range from about 6.3 l/s to a few hundred l/s (100 gpm to several thousand gpm).[11] The water is of good quality except in deep zones containing connate salty water and in tongues and wedges of salt water, which occur in all aquifers at or near the shoreline. Table 12 lists the stratigraphic units and the water-bearing properties of the unconsolidated rocks.

Table 11. LITHOLOGIC AND WATER-BEARING PROPERTIES OF CONSOLIDATED ROCKS IN VIRGINIA(11, 53, 54, 55)

Physiographic Province	Geologic Age	Principal Rock Type	Water-Bearing Properties Yield range in L/s (gpm)
Appalachian Plateau and Valley and Ridge	Chiefly Cambrian to Pennsylvanian	Sandstone	Water in openings along faults, joints, fractures and bedding planes; water quality generally good except locally near coal mining areas where acid and high iron conditions are common. Yields generally about 0.3 - 1.9 (5 - 30) but as much as a few tens of liters per second (several hundred gpm) locally.
		Shale	Occurrence of water same as above. Yields generally about 0.6 - 3 (10 to 50).
		Carbonates (Limestone and Dolomite)	Important aquifers. Water in openings along joints, fractures, bedding planes, solution channels, and cavities; hardness moderate to excessive, moderate to large yields.
Blue Ridge and Piedmont	Chiefly Precambrian to Ordovician	Igneous & Metamorphic (Granite, gneiss, schist, diorite, phyllite slate, quartzite, and marble)	Minor aquifers; Water mainly in openings along fractures, joints, and rock contacts, and in thick weathered residual deposits on bedrock surface; water is soft to moderately hard. Yields generally range from a few liters per second (few gallons per minute).
Piedmont	Triassic	Sandstone and conglomerate	Important aquifers locally; rocks occur in several elongated down-faulted basins; water in openings along bedding planes, joints, and faults, and in pore spaces; water moderately to highly mineralized; iron and sulfate are locally excessive; yields range from about 1.9 - 38 (30-600).
		Shale	Minor aquifers. Water in openings along joints, fractures, and bedding planes; yields generally less than 1.3 (20).
		Igneous (Diabase)	Minor scattered aquifers; water in openings along joints and fractures; yields generally less than 0.6 (10).

Table 11. GEOLOGIC UNITS AND THEIR CHARACTERISTICS - VIRGINIA COASTAL PLAIN[36, 37]

System	Series	Stratigraphic Units Richards (1967)	Stratigraphic Units Teifke (1973)	Generalized Lithology	Water-Bearing Properties
Quaternary	Pliocene-Holocene		Columbia Group	Chiefly sand and gravel; some silt and clay. Terrace, stream channel, and beach deposits	Water-table aquifer; water is soft; general quality is fair to good; iron content excessive locally; mainly for scattered rural and domestic supplies; low to moderate yield
Tertiary	Miocene	Yorktown Formation St Marys Formation Choptank Formation	Yorktown Formation (possibly Pliocene in part)	Silt, sand, cemented shell beds; glauconitic sand	Minor aquifers; confining unit in part; important source of water on Eastern Shore Peninsula; low to moderate yield
		Calvert Formation	Calvert Formation	Clay, silty clay, sandy clay, shells, and basal sand unit	Minor aquifers; hard water; mainly serves as a confining unit.
	Eocene	Chickahominy and Piney Point Fm.			
		Nanjemoy Formation	Nanjemoy Formation	Coarse quartz; glauconitic sand, shell beds, limestone, and clay	Minor aquifers; chloride content increases toward eastern shoreline.
		Aquia Formation	Mattaponi Formation	Glauconitic clay and sand, shell beds, dolomite, limestone, beds of clay; basal sand and gravel	Mainly minor aquifers; water soft to hard.
	Paleocene —?—?— Upper (?)	Mattaponi Formation			
Cretaceous	Upper	Raritan Formation	"transitional beds"	Fine sand and clay, clayey gravel, lignite	Major artesian aquifer; water soft to hard; increasing chloride content near shoreline; yields up to 125 (2,000).
	Lower	Patapsco Formation Arundel Formation			
		Patuxent Formation	Patuxent Formation	Mud to coarse sand and gravel; interbedded clay & silt. Underlain by crystalline basement rocks	

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SECTION V

NATURAL GROUND-WATER QUALITY

INTRODUCTION

Natural ground-water quality varies from region to region, as a result of geologic and climatic conditions. The chemical nature of ground water evolves from the interaction of water with rock materials and from the length of time water is in contact with these rocks. Natural ground-water quality is intimately related to the solubility of the minerals in the rocks through which the water moves, so that the chemical character of ground water generally can be associated with a particular rock type. Where the rocks are similar in composition over broad areas, the chemical character of the water is generally consistent. Where localized occurrences of soluble, atypical minerals are present, the chemical quality of local ground water reflects those minerals.

Because ground water is not static, but is constantly in motion, there commonly is a change in quality as water moves within an aquifer. At the point where the water first enters the ground its chemical character resembles that of rain water, but as it moves through the earth its composition is influenced more and more by the chemical character of the rocks. The capability of an aquifer to circulate water has a distinct influence on the mineral content. In the highly permeable, but areally limited, surficial sand aquifers, circulation is rapid and water quality is generally good. In extensive aquifers, however, water can migrate many miles from the intake area to the discharge area, and its mineral content generally increases due to the very long travel time associated with such a migration. Changes in the relative concentrations of some constituents occur, such as the softening that takes place during movement through greensands.

Consolidated rock aquifers are quite variable in their circulation capability, and generally, have only limited circulation below depths of about 152 m (500 ft). At greater depths, the water can be highly mineralized, with high chloride and total dissolved solids the primary objectionable constituents. Figure 18 is a map of the seven-state study area showing the depth to mineralized ground water in the major aquifers.

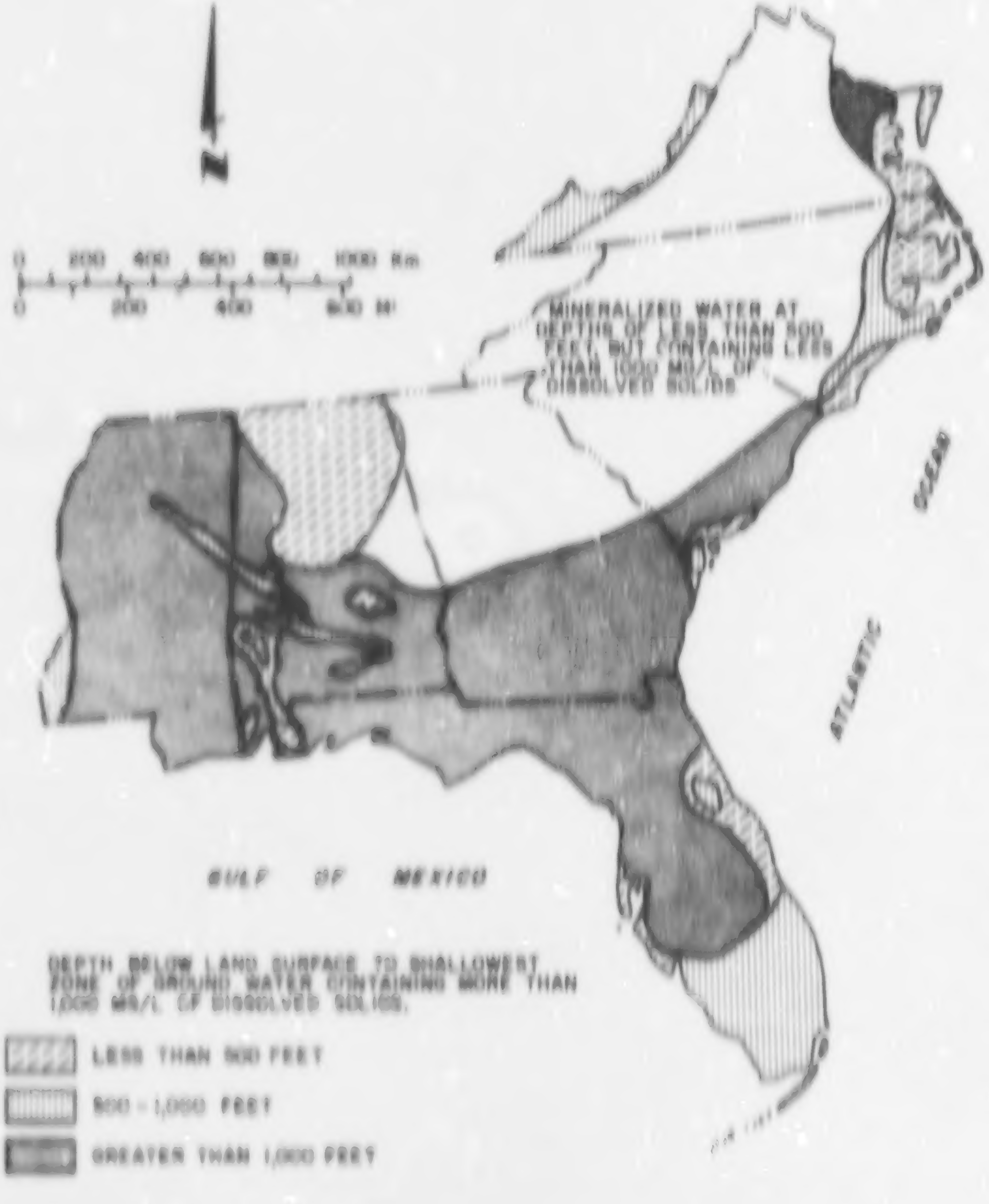
N
0 200 400 600 800 1000 Km
0 200 400 600 Mi
MINERALIZED WATER AT DEPTHS OF LESS THAN 500 FEET, BUT CONTAINING LESS THAN 1000 MG/L OF DISSOLVED SOLIDS
ATLANTIC OCEAN
GULF OF MEXICO
DEPTH BELOW LAND SURFACE TO SHALLOWEST ZONE OF GROUND WATER CONTAINING MORE THAN 1,000 MG/L OF DISSOLVED SOLIDS.
LESS THAN 500 FEET
500 - 1,000 FEET
GREATER THAN 1,000 FEET

Figure 18. Depth to mineralized ground water in major aquifers in the southeast United States.$^{11)}$

PRINCIPAL PROBLEMS OF NATURAL GROUND-WATER QUALITY

The principal problems of natural ground-water quality in the Southeast are, in order of importance:

1. Hardness
2. Iron
3. Fluoride
4. Corrosiveness
5. Radionuclides

Each of these quality problems is discussed below followed by a description of natural ground-water quality on a state-by-state basis. Evaluation of the relative quality of ground water is according to constituent limits for drinking water recommended by the U. S. Public Health Service.2)

Hardness

Hardness of water results from the solution of alkaline-earth minerals from the soil and rocks it passes through. It is usually entirely attributable to calcium and magnesium, and is expressed in terms of equivalent calcium carbonate. Water containing carbon dioxide or other acid constituents will readily dissolve carbonate minerals (principally in limestones and dolomites). Some portion of hardness may be due to the presence of gypsiferous beds in the rock.

Hard water is recognized by the scum or curd formed with soap. Hard water results in the clogging of boilers and pipes, and the coating of cooking vessels with a precipitate. The precipitate is some combination of insoluble carbonates and sulfates as well as silica.

Numerous aquifers of the Southeast contain hard water. An accepted classification of hardness is as follows:3)

Hardness range (mg/l of $CaCO_3$)	Description
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

The high hardness and associated high total dissolved solids content in ground water cause considerable economic damage to household appliances and plumbing (Table 13). Damages from mineralized ground water for the seven states are estimated to total some $144.4 million per year. Per-capita household damages in areas served by private water well systems range from a high of $10.97 in Florida to a low of $1.04 in South Carolina.4)

Iron

The occurrence of iron in ground water is due to the leaching of soluble iron from the rocks and sediments that serve as aquifers. Each of the seven states in the Southeast is bothered by locally excessive concentrations of iron in ground water. The U. S. Public Health Service's recommended limit for iron in drinking water is 0.3 mg/l.2) The limit is set not for health reasons, but entirely for esthetic and taste considerations.

Iron and manganese tend to precipitate as hydroxides and stain laundry and porcelain fixtures. Iron bacteria such as *Crenothrix* and *Leptothrix* will increase the clogging of well screens and water pipes by forming iron hydroxide slimes. Often, well users will note that their water is turbid with iron hydroxide particles. This is attributable to changes in ground-water level or rate of pumping that tend to loosen and flush out the deposited iron hydroxides from the well or plumbing fixtures.5)

Fluoride

Fluoride is present in nearly all igneous and metamorphic rocks, where it substitutes for the hydroxyl in mineral structures, principally in apatite, mica, and amphiboles. Bedded phosphate deposits often contain several percent fluoride. An additional source of fluoride is the mineral fluorite which occurs in both igneous and sedimentary rocks.

Fluorides in sufficient quantities are toxic to humans and may cause fluorosis and bone damage. Low concentrations of 0.8 to 1.5 mg/l in drinking water aid reduction of dental decay and are considered beneficial. Higher concentrations, up to 5 mg/l, may cause mottling of teeth, but no other harmful effects.6) U. S. Public Health Service drinking water standards set a recommended upper limit on fluoride that ranges from 0.8 to 1.7 mg/l based on the prevailing air temperature. Because more water is drunk in regions having warmer climates, the fluoride content in such regions should be lower to prevent excessive total fluoride intake. For

Table 13. HOUSEHOLD DAMAGES CAUSED BY USE OF MINERALIZED SURFACE AND GROUND WATER IN 1970[a)]

Total Household Damage, Million $[a)]

State	Public Water Supply Treated Surface Water	 Treated Ground Water	Private Well	Total
Alabama	6.3	3.4	3.3	13.0
Florida	5.3	40.8	18.6	64.7
Georgia	2.8	3.7	9.9	16.4
Mississippi	0.6	3.3	1.4	5.3
North Carolina	5.1	2.3	9.6	17.0
South Carolina	1.9	0.4	0.5	2.8
Virginia	11.4	2.8	11.0	25.2
Total:	33.4	56.7	54.3	144.4

Per Capita Household Damage, $[a)]

State	Public Water Supply Treated Surface Water	 Treated Ground Water	Private Well	Total
Alabama	3.76	3.79	3.81	3.78
Florida	9.60	8.99	10.97	9.51
Georgia	1.46	3.09	6.76	3.58
Mississippi	2.17	2.37	2.53	2.38
North Carolina	2.38	3.33	4.29	3.35
South Carolina	1.15	1.11	1.04	1.12
Virginia	3.95	6.21	8.43	5.43

a) Based on a 7.5 percent discount rate.

outright rejection of a water supply, the U. S. Public Health Service sets the standard at 1.4 to 2.4 mg/l or two times the optimum recommended level.

Corrosiveness

A ground-water quality problem which can directly affect health, and also cause economic loss of well equipment, plumbing, and household appliances, is the corrosive nature of certain waters. The hydrogeologic conditions that cause corrosive waters are generally the opposite of those causing encrustation and clogging of pipes. Encrusting waters are usually hard, of high total mineral content and alkaline in pH. Corrosive waters, not including saline waters, often have a low mineral content, high dissolved CO_2 content, are soft, and of acidic pH. Corrosive waters can occur in both the recharge area of the aquifer and down gradient.

Corrosiveness of ground water tends to be a problem in almost all of the sand aquifers, particularly in the outcrop areas of the sands. Additionally, the crystalline rocks of the Piedmont often yield acidic ground water. The median pH of waters from both such rock materials in the Southeast ranges from 5.7 to 7.0.

Radionuclides

Naturally radioactive substances in ground water are present in almost all rocks even though the amounts are often below detection limits. Development of the nuclear industry, nuclear weapons testing, and the related increase of radioactivity in the environment from fallout, required that limits be set on human exposure to radiation.

The Federal Radiation Council has provided criteria in establishing limits for radioactivity in drinking water. These limits are based upon three ranges of intake of radioactivity. For each range, a measure of control action has been defined as shown below:

Ranges of Transient Rates of Daily Intake	Graded Scale of Action
Range I	Periodic confirmatory surveillance as necessary
Range II	Quantitative surveillance and routine control

Range III	Evaluation and application of additional control measures as necessary

Limits have been set for daily intakes of radionuclides with the provision that dose rates be averaged over a period of one year. In the case of drinking water, recommended limits have been established for only two nuclides, namely radium-226, three pCi/l (picocuries per liter), and strontium-90, 10 pCi/l, although a great variety of radionuclides may be present. The accumulation of excessive radium and strontium from water constitutes a health hazard. These radionuclides ingested into the body are retained and deposited in the bones, and ultimately may produce bone cancer.

Specific data for the occurrence of radium-226 in ground waters of the southeast study area are presented in the following paragraphs rather than in the tabulations of selected chemical analyses for each state because the amount of data is so minimal. Additionally, information indicating that the ground water of certain geologic formations may naturally contain high levels of radium-226 was uncovered during the course of this study. These data are presented here because such radiation can pose a threat to the public.

An assessment of the levels of radium and uranium in ground waters of the United States was made from samples collected from 1952 to 1958. The radium (species undifferentiated) content of 80 ground water samples in the southeast ranged from less than 0.1 to 4.7 pCi/l.[7]

One of the South Carolina wells sampled in the above study with a reported radium (species undifferentiated) concentration of 4.7 pCi/l was resampled by the U. S. Geological Survey and found to have a radium-226 concentration of 5.7 pCi/l. Two additional wells not sampled previously but in the same geologic formation, the Orangeburg Group of Eocene Age, were sampled and were found to have concentrations of 4.6 and 7.1 pCi/l.[8]

Evidence that ground water in Cretaceous sands may also have localized high radium-226 levels comes from two wells sampled in Alabama: a 122-m (401-ft) deep well in the Ripley Sand yielded water with a radium-226 concentration of 2.1 pCi/l and a 311-m (1,020-ft) deep well in the Eutaw Formation had a concentration of 2.2 pCi/l.[9] It is possible that higher concentrations exist.

A study of 420 wells centering on the phosphate-producing area of southern Florida showed that 68 percent of them contained ground water with radium-226 levels higher than U. S. Public Health Service standards.[10] Exact analytical data have not been released. The geology of the area is such that the wells probably tap an aquifer which is composed of Miocene sediments; these rock units are those highest in phosphate content and also highest in fluoride content.[11]

A number of the geologic formations in the Southeast containing radioactive minerals have one thing in common: the presence of high amounts of organic matter in the form of lignite (plant matter subjected to a partial coalification process). The close relationship between carbonaceous material and uranium has long been noted by geologists working in the Colorado Plateau uranium-vanadium deposits.[12] Additionally, it has been shown that there is a direct correlation between organic carbon content and uranium content in coal fields.[13] Uranium deposits occur in the phosphates of Florida.[14] The phosphates occur as phosphatized bone and shell material, where phosphate replaces carbonate to form the mineral apatite.

Many of the geologic formations of the Coastal Plain of the Southeast contain high concentrations of carbonaceous matter, or evidence of past occurrence of organic matter around which uranium-bearing ground water or ancient ocean waters might have deposited uranium by a replacement or direct precipitation process. Geologic units that should be considered as more likely than others to contain ground water with radium-226 are: Cretaceous sands of Virginia; Peedee and Black Creek formation of Cretaceous age of North Carolina and South Carolina; Orangeburg Group of Middle and Upper Eocene age in South Carolina; Claiborne Group of Eocene age and Cretaceous sands in Georgia; Tuscaloosa, Eutaw and Ripley Formations of Cretaceous age and formations in the Eocene age Claiborne Group of Alabama; various lignitic units of the Claiborne Group and Cretaceous sands of Mississippi; and the phosphatic units such as the Miocene age Hawthorn, Alachua and Bone Valley Formations of Florida, the upper Miocene Duplin Marl of Georgia, and the Miocene units of South Carolina and North Carolina.

BASE-LINE GROUND-WATER QUALITY CONDITIONS

Natural ground-water quality conditions in each of the seven states are discussed below, based on a review of the literature. Most of the studies reviewed for the preparation of the data tables were made within the last 30 years and incorporated chemical analysis data extending back as much as 50 years. More recent changes in water quality stemming from man's activities may not be reflected in many of the published reports. The chemical analyses tables presented for each state show the number of samples (N), the range (R) in concentrations, the median value (M), or the mode value where median values could not be obtained.

Alabama

Ground water in Alabama has a natural chemical quality that is suitable for most purposes. In the coastal areas there is some high chloride due to salt-water encroachment.15) Excessively high fluoride levels are recorded from two of the aquifers and iron in the water is a problem in various aquifers. Table 14 is a compilation of selected chemical analyses of the ground water from the major Coastal Plain aquifer and from the aquifers of the Interior Low Plateau, Appalachian Plateau, and Valley and Ridge.

Most of the ground waters in Alabama are alkaline, soft to moderately hard, and of low to moderate mineral content. The Piedmont aquifers tend to yield slightly acidic ground waters with some locally high nitrate levels. The Interior Low Plateau, Appalachian Plateau, and Valley and Ridge ground waters have high fluoride and nitrate (NO_3) concentrations in some places. The Ripley, Nanafalia, and Gosport-Lisbon aquifers of the Coastal Plain have scattered occurrences of high nitrate in the ground water of their outcrop areas.

Of 611 water samples from wells tapping the major Coastal Plain aquifers in Alabama, 40 percent contained iron concentrations exceeding the recommended limit of 0.3 mg/l. In the Piedmont area and in the region comprising the Appalachian Plateau, Interior Low Plateau, and Valley and Ridge areas, the iron levels in the water exceeded the limit for 51 percent and 54 percent of the samples, respectively.9)

The fluoride content of the ground water of the Eutaw and Ripley aquifers of Cretaceous age in Alabama exceeded the recommended upper limit of 1.0 mg/l for 55 percent of 185 samples and for 26 percent of 101 samples, respectively.9) The high level of fluoride in certain Alabama ground waters was noted as early as 1940 and is attributed to fluoride in phosphate and volcanic ash deposits in the upper part of the formations. There seems to be a direct relationship between the presence of high fluoride concentrations in the water of these aquifers and the presence of soft water of high bicarbonate content in association with pyrite, lignite, phosphate, volcanic materials, and glauconite.16,17) The fluoride content of the water in the Nanafalia and Lisbon

Table 14. TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN ALABAMA [91]
Concentration in mg/l (milligrams per liter).

	Iron (Fe)			Sulfate (SO_4)			Chloride (Cl)		
Aquifer	N	R	M	N	R	M	N	R	M
Piedmont	103	0–7.6	0.4	120	0–40	2	184	0–71	4
Plateaus and Valley & Ridge	113	0–14	0.6	232	0–2520	8	995	0–2700	4
Tuscaloosa	236	0–29	0.5	184	0–285	5	358	0–4350	4
Eutaw	287	0–14	0.1	189	0–300	4	518	0–5690	8
Ripley	48	0–2.8	0.1	106	1–1120	21	104	2–1470	21
Clayton	4	0–1.0	—	8	0–106	—	8	4–310	11
Nanafalia	7	0–1.0	0.2	45	1–410	6	46	2–1870	9
Gosport-Lisbon	9	0–1.2	0.2	55	1–86	3	58	1–29	6
Miocene	20	0–13	0.3	66	0–70	5	89	1–2630	6

Table 14 (cont.) TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN ALABAMA [9]
Concentration in mg/l (milligrams per liter).

Aquifer	Hardness (CaCO$_3$)			pH		
	N	R	M	N	R	M
Piedmont	190	3-224	24	139	4.6-9.4	6.7
Plateaus and Valley & Ridge	1049	2-3540	106	245	4.6-8.8	7.6
Tuscaloosa	362	1-1530	18	292	3.9-11.6	7.8
Eutaw	520	0-680	22	431	4.5-9.8	7.9
Ripley	105	5-1890	64	71	4.8-9.2	7.7
Clayton	8	32-215	183	6	6.4-8.2	7.9
Nanafalia	44	5-245	61	14	5.7-8.6	7.6
Gosport-Lisbon	58	5-254	67	19	6.3-8.7	7.5
Miocene	85	1-166	19	52	4.9-8.5	7.4

Table 14 (cont.) TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN ALABAMA[9)]
Concentration in mg/l (milligrams per liter)

Aquifer	Fluoride (F)			Nitrate (NO_3)			Dissolved Solids Residue on Evaporation 180° C.		
	N	R	M	N	R	M	N	R	M
Piedmont	126	0-1.2	0.2	104	0-68	3	3	10-154	-
Plateaus and Valley & Ridge	144	0-7.5	0.1	196	0-83	1	88	12-3860	169
Tuscaloosa	184	0-2.4	0.1	100	0-28	0[a)]	64	16-5240	118
Eutaw	185	0-6.8	1.2	122	0-30	1	83	93-9425	225
Ripley	101	0-4.4	0.2	87	0-80	1	14	210-570	-
Clayton	8	0-1.6	0.1	8	0-9	1	—	——	-
Nanafalia	35	0-1.6	0.1	43	0-159	0[a)]	6	24-3490	-
Gosport-Lisbon	46	0-1.1	0.1	51	0-88	1	11	31-255	-
Miocene	63	0-1.4	0.1	60	0-17	0[a)]	12	25-4600	-

a) Mode.

aquifers is also higher than normal but does not approach the levels encountered in the Eutaw and Ripley aquifers.

Florida

Ground water in Florida is generally of good quality. Table 15 is a compilation of chemical analyses of selected constituents in natural ground waters of the various aquifers.

The major aquifer in Florida is the Floridan, which underlies the entire state. Water from this aquifer is generally hard, low in iron and fluoride, and is characterized by an acid to slightly alkaline pH in the recharge areas and an alkaline pH in the confined portion of the aquifer. Figure 11 shows the approximate areas where the Floridan and other aquifers are the main source of supply; however, the boundaries do not represent the areal extents of the aquifers. South of Lake Okeechobee and along the east coast north to St. Augustine, the Floridan aquifer water is generally not potable due to high total dissolved solids content.

The fluoride content of the Floridan aquifer water in the western part of the Florida Panhandle exceeds the recommended maximum of 1.0 mg/l in 28 percent of samples taken west of Apalachicola, and values as high as 13 mg/l are reported.40) The precise origin of the fluoride is unknown, but is most likely attributable to naturally occurring minerals that contain soluble fluoride.40) In the phosphate producing area of south-central Florida, fluoride in the ground water occurs in concentrations up to 4.0 mg/l, with the greatest amounts in the Hawthorn and Tampa formations.11)

The Biscayne aquifer contains ground water that is generally very hard, and 46 percent of the waters used in the ground-water quality comparisons contained greater than 0.3 mg/l iron. The ground water is more mineralized than that from other aquifers and is also the most alkaline (pH 7.8). The higher mineral content is attributable to residual saline waters which have not been flushed out.

In the Florida Panhandle, the Sand and Gravel aquifer is the principal source of ground water. The water is characterized by being very soft and low in mineral content. An acidic nature and high iron content (greater than 0.3 mg/l in 40 percent of the analyses), along with an apparent vulnerability to nitrate contamination, are other features of the water quality.

Table 15. TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN FLORIDA[18-39]
Concentration in mg/l (milligrams per liter)

Parameter		Shallow Aquifer	Sand & Gravel Aquifer	Biscayne Aquifer	Floridan[a] Aquifer
Iron	N	350	50	251	12
	R	0-6.4	0-4.0	0-8.8	0-0.21
	M	0.1	0.3	0.3	0.05
Sulfate (SO_4)	N	272	54	455	69
	R	0-1600	0-43	0-2500	0-440
	M	17	1	17	7
Chloride (Cl)	N	360	54	552	71
	R	2-1150	0-320	5-18,000	8-192
	M	21	3	28	11
Fluoride (F)	N	306	41	196	71
	R	0-3.1	0-0.5	0-0.9	0-1.7
	M	0.2	0.1	0.4	0.2
Nitrate (NO_3)	N	263	54	301	66
	R	0-120	0-20	0-16	0-12
	M	15	0.5	0.1	0.45
Dissolved Solids (Residue on Evap. at 180° C.)	N	272	54	445	70
	R	22-2660	6-654	58-33,000	95-804
	M	275	26	325	261
Hardness ($CaCO_3$)	N	424	54	494	70
	R	2-1910	0-135	22-6150	45-625
	M	140	4.5	276	251
pH	N	372	55	213	71
	R	4.2-9.2	4.9-6.0	6.4-8.6	6.2-8.6
	M	7.4	6.4	7.8	7.5[b]

a) Represents 1970 withdrawals of 1.05 hm^3/day (277 mgd) or 44 percent of the total public water supply obtained from ground-water sources.[26]

b) pH of the Floridan aquifer is bimodal (7.2 and 8.3)

Covering most of Florida and serving as a source of water supply for domestic wells and irrigation wells, the shallow aquifers contain water that is generally alkaline, hard, and of low iron content. However, the aquifer appears to be susceptible to nitrate contamination. Nine percent of the samples contained greater than 0.8 mg/l fluoride, which is the U. S. Public Health Service recommended maximum for eastern and southern Florida where this aquifer is used most intensely. The mineral content is quite variable due to the various lithologies of the rock units making up the shallow aquifer.

The location of the fresh and brackish water in the Floridan Aquifer is shown on Figure 19.[41] This position of saline water (greater than 1,000 mg/l TDS) is attributable primarily to geological controls and saline water that has not been flushed out of the aquifer.

Georgia

The ground water of Georgia is suitable for most purposes, and there are few serious quality problems. Those that do exist are related to such factors as hardness, iron content, corrosiveness, and residual salinity. Table 16 is a compilation of selected ground-water chemical analyses for the major Coastal Plain aquifers, and for the aquifers of the Piedmont-Blue Ridge and Valley and Ridge (Paleozoic) areas.

Ground water in the Valley and Ridge area is generally of good quality, although the carbonate rocks yield hard water. Water from the sandstone and shale is soft, but often corrosive and high in iron content. In certain areas the deeper waters may be slightly saline.

The Piedmont-Blue Ridge rocks, because of their less soluble nature, yield soft water of low to moderate mineral content. However, such waters tend to be corrosive and high in iron.[52]

The aquifers of the upper Coastal Plain yield ground water of generally good quality, although the sands yield water that is somewhat corrosive and may have a high iron content. Downgradient, these waters become saline which generally poses no real problem as there are other productive aquifers above the saline waters.

The principal artesian aquifer of the lower Coastal Plain contains ground water that is of good quality, although hard. The dissolved solids content is moderately high, but generally less than 600 mg/l. Highly mineralized water is

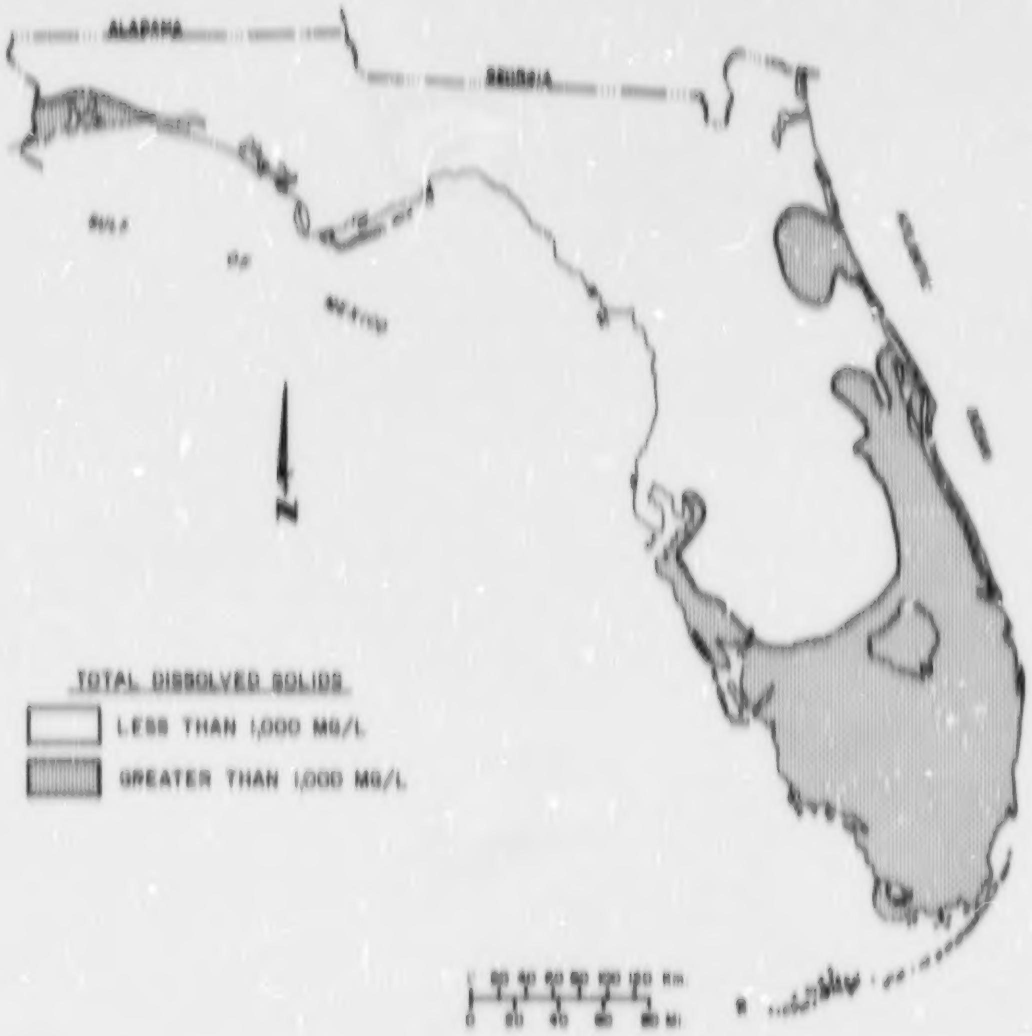
ALABAMA
GEORGIA
GULF OF MEXICO
ATLANTIC OCEAN
N
TOTAL DISSOLVED SOLIDS
LESS THAN 1,000 MG/L
GREATER THAN 1,000 MG/L
0 20 40 60 80 100 120 Km
0 20 40 60 80 Mi

Figure 19. Dissolved solids in water from the upper part of the Floridan Aquifer in Florida.41)

Table 16. TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN GEORGIA[illegible]
Concentration in mg/l (milligrams per liter)

Aquifer	Iron (Fe)			Sulfate (SO_4)			Chloride (Cl)		
	N	R	M	N	R	M	N	R	M
Piedmont- Blue Ridge	82	0-6.8	0.2	82	0-598	6	92	0-3820	5
Paleozoic (Valley & Ridge)	137	0-2.6	0.1	142	0-277	3	143	0-1394	3
Upper Coastal Plain Sands	52	0-5.4	0.2	75	0-35	1	77	1-25	3
Upper Coastal Plain Carbonates & Sands	33	0-1.8	0.1	68	0-27	6	56	0-24	3
Lower Coastal Plain Principal Artesian Aquifer	67	0-2.4	0.1	69	0-952	26	70	2-2800	5
Lower Coastal Plain Miocene	11	0-1.0	0[a]	14	0-28	2	26	2-66	7

a) mode

Table 16 (cont). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN GEORGIA$^{43-52}$
Concentration in mg/l (milligrams per liter)

Aquifer	Hardness (CaCO$_3$)			pH		
	N	R	M	N	R	M
Piedmont- Blue Ridge	74	0-1090	46	77	5.1-8.8	6.4
Paleozoic (Valley & Ridge)	134	4-446	256	135	4.6-9.9	7.5
Upper Coastal Plain Sands	72	4-157	21	28	3.7-8.5	6.5
Upper Coastal Plain Carbonates & Sands	67	6-252	114	27	5.2-8.8	7.6
Lower Coastal Plain Principal Artesian Aquifer	64	50-1410	195	78	7.3-8.1	7.7
Lower Coastal Plain Miocene	24	8-155	—	12	6.4-8.1	—

Table 16 (cont.). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN GEORGIA[42-61]
Concentration in mg/l (Milligrams per liter)

Aquifer	Fluoride (F)			Nitrate (NO_3)			Dissolved Solids (Residue on evaporation 180° C.)		
	N	R	M	N	R	M	N	R	M
Piedmont- Blue Ridge	68	0–0.4	0[a]	68	0–113	0[a]	84	19–7230	107
Paleozoic (Valley & Ridge)	133	0–1.5	0.1	136	0–22	1	86	32–636	151
Upper Coastal Plain Sands	68	0–1.0	0[a]	57	0–32	0[a]	31	18–325	51
Upper Coastal Plain Carbonates & Sands	58	0–0.5	0.1	67	0–56	1	21	31–261	155
Lower Coastal Plain Principal Artesian Aquifer	70	0–1.2	0.4	67	0–19	0[a]	68	103–4350	225
Lower Coastal Plain Miocene	14	0–0.5	0.2	13	0–21	8	16	26–226	—

a) mode

a problem near the Atlantic coast of Georgia and inland along the Florida border.[42,62,63] The upper zone of the principal artesian aquifer commonly contains water with hydrogen sulfide gas, and the lower zone of this aquifer commonly has a high sulfate content.[42,63] Little is known about the base of fresh ground water in most of Georgia because the fresh water zone is so thick that there has been little need for deep drilling.

Mississippi

The natural quality of the ground water in Mississippi is good for most purposes, although minor problems are present at certain locations. High iron concentration, low pH, excessive carbon dioxide content, and color are the principal problems.

Table 17 is a compilation of ground-water chemical analyses from the major aquifers, taken from published reports. Usually the water from the deeper zones of the aquifers is of better quality than that obtained from the shallow zones. Waters in the outcrop areas of the aquifers, although of a lower mineral content than that of the deeper zones, are harder, have a low pH, are high in iron and carbon dioxide content, and contain the highest concentrations of nitrate.

Analyses of 671 water samples from wells tapping the major aquifers in Mississippi show that 38 percent contained iron concentrations exceeding 0.3 mg/l. The aquifers most often exceeding the limit are the alluvium, the Miocene aquifers, some sands of the Tallahatta Formation, and the Tuscaloosa and Wilcox Groups.

Locally, the fluoride concentration of ground water in the Cretaceous aquifers (Eutaw and Tuscaloosa) exceeds the recommended health limit. However, fluoride concentrations in Mississippi ground waters are generally low.

Organic color in ground water is a problem in certain aquifers, particularly the Kosciusko (Sparta Sand) and Cockfield aquifers in some areas of the central portion of the state, and some of the deeper Miocene aquifers along the Coast. The color originates from organic material (lignitic) within the aquifer.[67,68,70,71]

The position of the base of fresh ground water (total dissolved solids content less than 1,000 mg/l) is fairly well known. Figure 20 shows the configuration of the base of fresh water in Mississippi.[73,74,75] The total dissolved solids content increases with depth for many of the aquifers.

Table 17. TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MISSISSIPPI.(64-72)
Concentration in mg/l (milligrams per liter).

Aquifer	Iron (Fe) N	Iron (Fe) R	Iron (Fe) M	Sulfate (SO_4) N	Sulfate (SO_4) R	Sulfate (SO_4) M	Chloride (Cl) N	Chloride (Cl) R	Chloride (Cl) M
Paleozoic	2	0.3–25	—	2	9.4–12	—	2	5.5–100	—
Tuscaloosa	25	0–14	0.4	26	0–16	1.6	29	1–335	22
Eutaw	33	0–1.4	0.2	32	0–34	3.8	33	2–654	57
Ripley	7	0.1–1.1	0.2	6	3.6–132	8.9	7	1.2–9	3
Wilcox	80	0–14	0.3	94	0–36	5.9	94	1.2–725	6
Tallahatta	128	0–21	0.2	119	0–121	7	128	5–868	5
Kosciusko (Sparta)	74	0–18	0.1	76	0–26	8.2	76	1.7–81	6
Cockfield	74	0–14	0.2	73	0–203	36	75	2.8–532	23
Miocene	185	0–23	0.3	211	0–75	5	213	0–756	5
Graham Ferry	45	0–6.3	0.1	57	0.7–26	8.1	68	2–271	6
Citronelle	15	0–1.2	0.1	20	0–31	1	20	1.2–58	18
Alluvium	3	0.1–16	—	5	0–24	2	7	0–26	6

Table 17 (cont.) TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MISSISSIPPI[64-72]
Concentration in mg/l (milligrams per liter)

Aquifer	Fluoride (F)			Nitrate (NO_3)			Dissolved Solids (Residue on Evaporation 180° C)		
	N	R	M	N	R	M	N	R	M
Paleozoic	2	0.3–0.7	—	1	0.2	—	2	115–321	—
Tuscaloosa	22	0–1.1	0.3	28	0–3	0.4	28	27–722	180
Eutaw	29	0–5	0.3	30	0–7.6	6.7	33	70–1,080	266
Ripley	6	0.2–1.3	0.7	5	1.2–4.4	2.3	7	170–489	261
Wilcox	89	0–1.8	0.1	74	0–41	0.1	82	40–1,938	162
Tallahatta	115	0–4	0.1	65	0–27	0.3	119	33–2,666	297
Kosciusko (Sparta)	67	0–2.3	0.1	60	0–6	0.3	72	25–780	288
Cockfield	69	0–3	0.1	41	0–2.8	0.3	74	39–1,418	349
Miocene	182	0–1.3	0.1	178	0–52	0.2	181	20–1,637	135
Graham Ferry	24	0–0.7	0.1	20	0–1.2	0.1	41	252–618	228
Citronelle	28	0–0.2	0.1	19	0.3–29	2.7	25	27–256	64
Alluvium	5	0–0.3	0.2	5	0.1–2.5	0.8	7	33–261	307

Table 17 (cont.) TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MISSISSIPPI(64-72)
Concentration in mg/l (milligrams per liter)

Aquifer	Hardness ($CaCO_3$)			pH		
	N	R	M	N	R	M
Paleozoic	2	84-90	—	2	7.4-7.6	—
Tuscaloosa	28	6-70	34	26	5.3-8.5	7.6
Eutaw	32	2-153	42	32	6.4-8.2	7.9
Ripley	7	16-207	39	7	7.5-8.4	8.2
Wilcox	86	0-134	22	92	5.3-8.7	7.2
Tallahatta	121	0-170	12	121	5.2-9.0	7.5
Kosciusko (Sparta)	74	0-176	15	72	5.2-9.0	7.2
Cockfield	75	0-428	75	74	5.8-8.9	7.8
Miocene	213	0-142	12	242	4.6-9.1	6.7
Graham Ferry	58	2-20	8	22	5.8-9.2	8.0
Citronelle	20	4-52	17	15	5 2-7.5	5.9
Alluvium	7	6-300	260	7	5.3-7.5	7.2

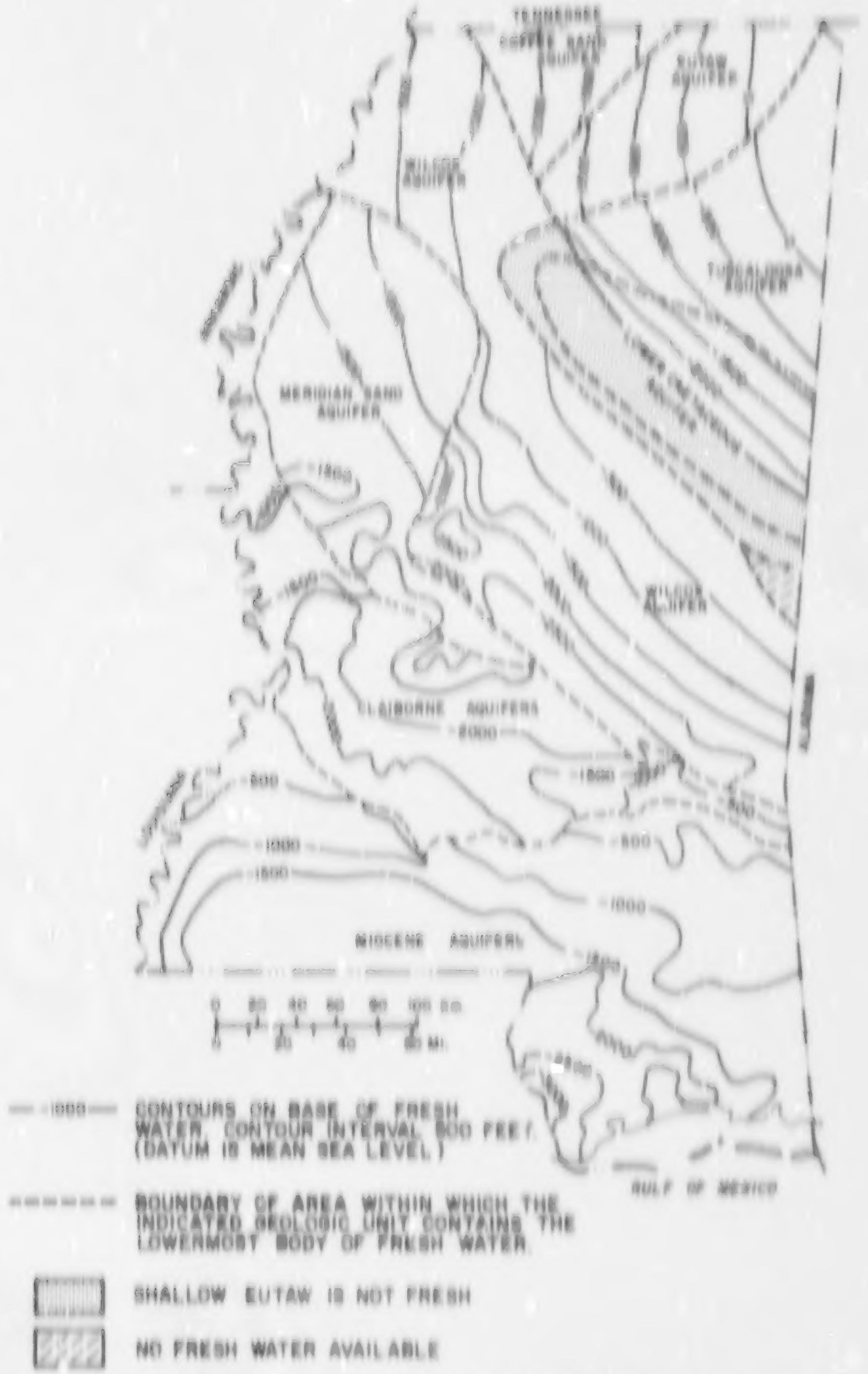
TENNESSEE
COFFEE SAND AQUIFER
EUTAW AQUIFER
WILCOX AQUIFER
TUSCALOOSA AQUIFER
ARKANSAS
MERIDIAN SAND AQUIFER
1500
WILCOX AQUIFER
CLAIBORNE AQUIFERS
2000
1500
500
1000
1500
500
1000
LOUISIANA
ALABAMA
MIOCENE AQUIFERS
1500
2500
0 20 40 60 80 100 KM
0 20 40 60 MI
GULF OF MEXICO
N
—1000— CONTOURS ON BASE OF FRESH WATER. CONTOUR INTERVAL 500 FEET. (DATUM IS MEAN SEA LEVEL)
– – – – – – BOUNDARY OF AREA WITHIN WHICH THE INDICATED GEOLOGIC UNIT CONTAINS THE LOWERMOST BODY OF FRESH WATER.
SHALLOW EUTAW IS NOT FRESH
NO FRESH WATER AVAILABLE

Figure 20. Base of the fresh ground water in aquifers in Mississippi.73)

Numerous salt domes penetrate the sedimentary strata of southern Mississippi (Figure 7), and the presence of these domes results in the base of fresh water being much higher than in areas away from the domes.[76]

North Carolina

The natural quality of ground water in North Carolina is variable among aquifers but is good overall. Table 18 is a compilation of chemical analyses of selected constituents in natural ground water. Ground-water quality problems are minor, related to locally high concentrations of iron or excessive hardness. Some of the waters from the Coastal Plain sands tend to be corrosive; others contain high levels of fluoride.

The igneous and metamorphic rocks of the North Carolina Piedmont vary considerably in chemical composition, and each major rock type yields ground water having a distinctive chemical character. In terms of chemical character of the water derived from them, the rocks may conveniently be divided into two groups. The first includes granite, granite gneiss, mica schist, slate, and rhyolite flows and tuffs; these rocks approximate granite in composition and are rich in silica and poor in calcium and magnesium. The second group includes diorite, gabbro, hornblende gneiss, and andesite flows and tuffs; these rocks approximate diorite in composition and are poorer in silica and richer in calcium, magnesium, and iron. The granite group yields a soft, slightly acidic water that is low in dissolved mineral constituents; in contrast, the diorite group yields a hard, slightly alkaline water that is high in dissolved minerals.[95]

Ground water in the consolidated sedimentary rocks of Triassic age in central North Carolina tends to be slightly hard to hard. Locally the water contains as much as 500 mg/l of chloride. Ground water in the Triassic rocks is generally satisfactory for domestic use, however.

Ground water from the lenticular Cretaceous Tuscaloosa sand beds of the inner Coastal Plain is low in mineral matter, the dissolved solids ranging from about 15 to 100 mg/l and the hardness ranging from about 5 to 75 mg/l. As the water from this aquifer is slightly acid (pH as low as 4.7) and the mineral content is low, the water tends to be corrosive.

Waters from the Cretaceous Black Creek and Peedee formations have enough similarity to be grouped together as a relatively high bicarbonate water. As a result of the natural softening capacity of some sand and clay beds, the water

Table 13. TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN NORTH CAROLINA.[77-94]
Concentration in mg/l (milligrams per liter).

Aquifer	Iron (Fe)			Sulfate (SO_4)			Chloride (Cl)		
	N	R	M	N	R	M	N	R	M
Pre-Cretaceous granite-type	29	0.02–8.7	0.2	29	0.1–23	2	29	1.1–27	2
Pre-Cretaceous diorite-type	23	0.0–5.7	0.2	23	0.1–391	44	23	1.4–204	20
Triassic Sedimentary	15	0.0–3.8	0.1	15	1.0–32	22	15	3–744	35
Tuscaloosa	11	0.05–3.0	0.2	11	1.0–15	2	11	3–25	12
Peedee and Black Creek	25	0.04–2.2	0.2	25	0.4–22	2	25	3–52	5
Castle Hayne	65	0.0–7.2	0.2	65	0.0–58	2	65	4–405	13
Quaternary Water-table Sands	18	0.1–21	0.4	18	2.0–20	4	20	3–62	25

Table 18 (cont.) TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN NORTH CAROLINA 77-94)
Concentration in mg/l (Milligrams per liter)

Aquifer	Fluoride (F) N	Fluoride (F) R	Fluoride (F) M	Nitrate (NO₃) N	Nitrate (NO₃) R	Nitrate (NO₃) M	Dissolved Solids (Residue on Evaporation 180° C.) N	Dissolved Solids (Residue on Evaporation 180° C.) R	Dissolved Solids (Residue on Evaporation 180° C.) M
Pre-Cretaceous granite-type	388	0-1.5	0.1	367	0-96	1	29	25-123	71
Pre-Cretaceous diorite-type	101	0-2.2	0.1	99	0-75	1	23	126-696	269
Triassic Sedimentary	27	0-1.5	0.1	21	0-89	0[a]	15	43-1166	140
Tuscaloosa	10	0-0.9	0.2	10	0-24	0[a]	11	28-115	42
Peedee and Black Creek	103	0-7.3	0.7	89	0-5	0[a]	25	56-420	170
Castle Hayne	64	0-1.4	0.3	56	0-9	0[a]	65	107-1010	258
Quaternary Water-table Sands	58	0-1.6	0.1	55	0-66	1	10	26-255	37

a) mode

Table 16 (cont.) TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN NORTH CAROLINA[77-94]
Concentration in mg/l (Milligrams per liter)

Aquifer	Hardness ($CaCO_3$)			pH		
	N	R	M	N	R	M
Pre-Cretaceous granite-type	29	8-58	23	29	5.8-7.2	6.5
Pre-Cretaceous diorite-type	23	52-402	172	23	6.5-8.2	7.1
Triassic Sedimentary	15	12-1168	74	15	5.8-7.6	7.2
Tuscaloosa	11	5-90	18	11	5.2-6.9	6.8
Peedee and Black Creek	25	5-283	74	25	6.2-8.4	7.6
Castle Hayne	65	12-461	192	65	5.7-8.1	7.3
Quaternary Water-table Sands	18	4-60	21	18	5.2-6.7	5.7

passes through a slightly hard calcium bicarbonate state to a soft sodium bicarbonate state as it moves deeper and coastward in the aquifers. Most of the water deeper than 91 m (300 ft) tends to have a hardness of less than 50 mg/l and a bicarbonate content greater than 150 mg/l. This soft sodium bicarbonate water is excellent for most uses. Most of the water contains slightly less than one mg/l of fluoride, but in a belt extending from the central portion of the Coastal Plain northeast to the Virginia line, some of the water from the aquifer contains enough fluoride to mottle the enamel of teeth.96) Approximately 24 percent of the ground-water analyses from the Black Creek and Peedee formations show concentrations exceeding 1.5 mg/l of fluoride.

Water quality in the limestone aquifer (chiefly the Castle Hayne Formation) is closely related to the solubility of these deposits. The chief mineral constituents in solution are calcium and bicarbonate, and the median hardness is about 190 mg/l. Locally the water contains objectional quantities of iron. A slight odor of hydrogen sulfide is commonly present.

The Quaternary sand water-table aquifer, which is the shallow aquifer throughout the Coastal Plain, contains water that is soft and low in total dissolved solids. The water has a low pH value and is almost everywhere corrosive.

In most places below a depth of about 152 m (500 ft) the water is salty, although the boundary between fresh and salty water crosses formational contacts and is very irregular. The salinity tends to increase with depth. Along the coastal areas the Cretaceous aquifers are deeply buried and contain connate salty water.

South Carolina

The natural quality of ground water in South Carolina is suitable for most purposes. High iron concentration, low pH, high fluoride, excessive hardness, and high chloride are the principal problems, but alternate sources of better quality water are locally available from other aquifers.

Table 19 is a compilation of selected ground-water chemical analyses for the Piedmont-Blue Ridge aquifer and the major Coastal Plain aquifers. Ground-water quality data are not as plentiful as for other areas because of the emphasis that has been placed on the development of surface supplies. In addition, the ground water is of such good quality that there has been little reason for extensive studies.

Table 13. TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN SOUTH CAROLINA[8,97,98,99]
Concentration in mg/l (milligrams per liter)

Aquifer	Iron (Fe)			Sulfate (SO_4)			Chloride (Cl)		
	N	R	M	N	R	M	N	R	M
Piedmont-Blue Ridge	13	0-24	0.1	13	0-279	2	13	1-16	6
Tuscaloosa	9	0-1.6	0.1	12	1-11	8	18	2-57	3
Peedee-Black Creek	21	0-4.0	0.1	31	0-2150	6	31	1-13,900	6
Orangeburg (Barnwell, McBean, Warley Hill, Congaree)	25	0-1.1	0.2	13	0-9	1	24	2-16	5
Santee Limestone	13	0-6.3	0.4	11	2-109	5	11	1-1330	6
Ocala Limestone	33	0-3.8	0.1	33	2-775	22	33	4-2020	53

Table 19 (cont.) TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN SOUTH CAROLINA[illegible]
Concentration in mg/l (milligrams per liter)

Aquifer	Hardness (CaCO$_3$) M	Hardness (CaCO$_3$) R	Hardness (CaCO$_3$) n	pH N	pH R	pH M
Piedmont-Blue Ridge	46	7-1170	34	251	5.4-7.9	6.5
Tuscaloosa	—	--	—	25	4.2-8.6	6.4
Peedee-Black Creek	—	—	—	5	7.3-8.1	7.7
Orangeburg (Barnwell, McBean, Warley Hill, Congaree)	13	4-49	6	23	4.2-7.3	5.6
Santee Limestone	71	11-265	107	16	4.6-7.9	7.4
Ocala Limestone	—	—	—	32	7.3-8.5	7.9

Table 19 (cont.) TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN SOUTH CAROLINA[8,97,98,99]
Concentration in mg/l (Milligrams per liter)

Aquifer	Fluoride (F)			Nitrate (NO$_3$)			Dissolved Solids (Residue on Evaporation 180° C.)		
	N	R	M	N	R	M	N	R	M
Piedmont-Blue Ridge	11	0-0.5	0.2	23	0-9	1	11	20-526	99
Tuscaloosa	18	0-3.0	0.2	11	0-1	0[a]	17	20-772	66
Peedee-Black Creek	27	0-4.4	0.5	25	0-37	0[a]	29	27-27,700	167
Orangeburg (Barnwell, McBean, Warley Hill, Congaree)	12	0-0.7	0[a]	24	0-26	6	12	18-142[b]	24
Santee Limestone	11	0-2.2	0.1	16	0-10	0[a]	12	136-2830[b]	186
Ocala Limestone	33	0.1-2.6	0.7	33	0-6	0[a]	31	160-4620	306

a) mode
b) dissolved solids calculated

The aquifers most often containing ground water with naturally high levels of iron are those composed of sands of Cretaceous and Tertiary age in a belt 9 km (15 mi) wide extending from southwest to northeast across the central portion of the Coastal Plain.[100] Locally high levels of iron occur in the ground waters of the Piedmont.

Ground water contained in the Santee and Ocala limestones has a considerably higher level of hardness than that of the Cretaceous and Tertiary sands. The ground water of the Santee and Ocala limestones is in general more mineralized than that of any of the other aquifers except for the Peedee-Black Creek.

The ground water of Cretaceous and Tertiary sands tends to be quite acidic and corrosive, whereas that of the limestones is very alkaline.[101] Waters from the McBean and Congaree Formations are extremely acidic, with pH as low as 4.1.[8] This is attributed to the dissolution of pyrite and formation of hydrogen sulfide in the water.

Ground water in the southern coastal Tertiary limestones has a high chloride concentration which is attributed to incomplete flushing of connate waters[100] or to erosion of the overlying impermeable Hawthorn Formation and entrance of sea water into the limestone.[102]

Virginia

Ground water in Virginia is generally of good quality. Table 20 is a compilation of chemical analyses of selected constituents in Virginia ground waters. Minor reported quality problems are related to locally high levels of iron, chloride, fluoride or hardness. In most cases an alternate aquifer is available for water supply.

Ground waters of the Valley and Ridge carbonate aquifers are moderately mineralized and hard, whereas waters from the sandstone and shale aquifers are softer but locally higher in iron content. Ground water in the aquifers of the Appalachian Plateau is often acidic and contains iron in the vicinity of coal-mining areas.

The Blue Ridge and Piedmont aquifers contain moderately mineralized, soft to moderately hard water with iron locally. Ground-water quality data for the Triassic aquifers are sparse, but the waters tend to be somewhat mineralized and hard.

Table 20. TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN VIRGINIA[103-108]
Concentration in mg/l (milligrams per liter)

Aquifer	Iron (Fe) N	Iron (Fe) R	Iron (Fe) M	Sulfate (SO_4) N	Sulfate (SO_4) R	Sulfate (SO_4) M	Chloride (Cl) N	Chloride (Cl) R	Chloride (Cl) M
Valley & Ridge and Appalachian Plateau—shale and sandstone	18	0–6.6	0.2	23	1–349	5	22	0–298	1
Valley & Ridge and Appalachian Plateau carbonates	25	0–4.7	0[a]	79	0–78	6	76	0–295	1
Blue Ridge-Piedmont igneous and metamorphic	46	0–4.6	0.2	52	0–333	4	55	1–755	6
Triassic	3	0.3–1.8	—	2	5–11	–	5	5–40	–
Cretaceous	57	0–25	0.2	76	1–234	12	75	1–1820	3
Tertiary	55	0–19	0.1	97	0–400	7	92	1–2200	21
Quaternary	13	0–41	0.1	23	1–125	15	22	1–360	21

a) mode

Table 20 (cont.) TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN VIRGINIA[123-129]
(Concentration in mg/l (milligrams per liter)

Aquifer	Fluoride (F)			Nitrate (NO_3)			Dissolved Solids (residue on evaporation 180° C.)		
	N	R	M	N	R	M	N	R	M
Valley & Ridge and Appalachian Plateau—shale and sandstone	8	0–1.4	0.2	22	0–4	1[a]	20	40–865	-
Valley & Ridge and Appalachian Plateau carbonates	23	0–2.3	0.2	78	0–9	2	69	52–1290	173
Blue Ridge-Piedmont igneous and meta-morphic	44	0–16	0.3	47	0–9	1[a]	45	11–857	127
Triassic	1	0.3	—	5	0–36	—	4	292–411	-
Cretaceous	59	0–7.4	1.0	65	0–5	1[a]	46	85–4300	244
Tertiary	81	0–4.3	0.3	73	0–5	1	66	123–3777	266
Quaternary	16	0–0.5	0.1	20	0–22	2	16	15–814	—

a) mode

Table 23 (cont.) TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN VIRGINIA[103-109]
Concentration in mg/l (milligrams per liter)

Aquifer	Hardness ($CaCO_3$) N	R	M	pH N	R	M
Valley & Ridge and Appalachian Plateaus—shale and sandstone	24	38–1152	114	9	6.0–8.1	7.5
Valley & Ridge and Appalachian Plateaus carbonates	78	27–322	142	22	6.0–8.0	7.4
Blue Ridge-Piedmont igneous and metamorphic	56	2–758	54	44	5.4–9.4	6.9
Triassic	2	123–344	-	2	7.1–7.7	-
Cretaceous	61	2–186	28	25	6.7–8.7	8.3
Tertiary	86	7–347	90	45	6.4–8.5	7.9
Quaternary	23	7–526	45	8	5.7–7.9	6.4

The ground water of the Coastal Plain is low to moderately mineralized and of moderate hardness near the Fall Line (Piedmont-Coastal Plain contact), but becomes softer and more mineralized toward the Atlantic coast. The aquifers contain high levels of dissolved iron locally. Additionally, the Tertiary aquifers of Virginia are less calcareous than similar aquifers in the states to the south, and hence contain softer water.

The ground water contained in the Cretaceous aquifers of Virginia has a very high fluoride content. The fluoride in these aquifers exceeds 1.5 mg/l for 37 percent of the 57 samples used in the natural water-quality compilation. High concentrations of fluoride are also present in the ground water of some of the Tertiary aquifers.

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SECTION VI

SOURCES OF GROUND-WATER CONTAMINATION

DEFINITION OF THE PROBLEM

For many years, public agencies on all levels of government have been concerned about the contamination of surface waters. The loss of rivers and lakes as sources of water supply and for recreation can have a tremendous impact on a particular region, leading to construction of a long pipeline to import acceptable water, for example, or the closing of a popular swimming area to local residents. Degradation of the quality of water in a stream or lake can be rather obvious through discoloration, odor, and floating debris.

Problems of ground-water contamination, on the other hand, have never received much attention because they are usually localized and the effects are hidden from view. Only when a regional water source is threatened, due to problems such as salt-water encroachment or pollution from septic tanks, are controls recommended and implemented. However, protection of ground-water resources from all types of pollutants is an essential part of any program involving the solution of environmental problems. In many ways, the correction of ground-water quality degradation is considerably more complex than in the case of surface waters.

The impact of ground-water contamination in the Southeast takes on many aspects including:

1. The important role of ground water as a water-supply source.

2. The technical difficulties and high costs associated with the investigation, control, and correction of ground-water pollution.

3. The hidden and often misunderstood nature of ground-water pollution and the resulting health hazards and other effects.

4. The interrelationship of surface-water quality and ground-water quality.

5. The problems involved in monitoring ground-water quality.

Importance of the Resource

In the seven southeastern states covered in this report, ground water plays a major role in meeting the water-supply requirements of communities, individual homes, commercial establishments, self-supplied industrial facilities, and irrigated farms. Total ground-water use in the region in 1970 has been estimated at more than 20.7 cu hm/d (5.5 bgd), which is 46 percent of all the fresh water diverted for all purposes exclusive of that used for the generation of thermoelectric and hydroelectric power.[1]

Ground water plays a significant role with regard to rural populations and those not served by community systems. The rapid growth of suburbs in areas around major cities in the region has outpaced the ability of local utilities to build the necessary supply facilities, and consequently, more and more homes and small commercial establishments have constructed their own on-site water supplies. Invariably, they depend on drilled wells. The widespread use of ground water is possible because almost all of the rock formations are capable of yielding at least the few gallons per minute required to supply a single home or store.

Probably several million domestic wells are presently in use within the seven states. Table 21 shows by state the estimated number of wells constructed in 1964 in the region; the figures represent mostly domestic wells.

Ground water for domestic-type water supply development is available almost everywhere within the region, and many of the aquifer systems are capable of producing several thousand gallons per minute to properly developed individual wells. Reliance on ground water will increase in the region in the future, not only because of its widespread availability but because surface waters are becoming increasingly more difficult and expensive to develop. Some principal causes for this include the rising costs of treating surface waters, the stricter regulations being imposed by public health agencies with regard to water treatment, and the problems inherent in obtaining large tracts of land for surface reservoirs. In addition, there is the competition for surface-water rights and the more active environmental concern over the effects of surface-water diversions. Finally, the extreme drought conditions experienced in the region from time to time have revealed to many water managers the vulnerability of surface water during adverse climatic conditions. Because of this, a large number of high-capacity wells have been installed as back-up systems for some municipal and industrial surface-water supplies.

Table 21. NUMBER OF WELLS DRILLED IN THE SOUTHEAST IN 1964[2]

State	Estimated number of wells drilled
Alabama	4,500
Florida	55,000
Georgia	10,000
Mississippi	5,900
North Carolina	25,000
South Carolina	5,400
Virginia	10,000
Total	115,800

In summary, the availability of high-quality ground water is essential to the physical and economic well-being of the region, and the loss of aquifers or portions of aquifers due to contamination must be avoided.

Technical and Economic Difficulties

One particular aspect of ground-water contamination that makes it quite different from river pollution, and in many ways a more difficult problem to solve, is the long period of time required for decay, sorption, or dispersion of the contaminant in the ground-water system even if the source of contamination is removed. Correcting a situation causing ground-water contamination, such as lining a leaky basin into which a liquid industrial waste has been discharged, will prevent additional highly mineralized fluid from arriving at the water table but will not eliminate the problem itself. Because the polluted ground-water body normally moves and disperses slowly, and is affected very little by dilution from the recharge of or mixing with unaffected water, contaminants in ground water tend to be reduced in concentration over a period usually measured in years and even decades. In fact, long after a source of pollution has been removed, the contaminated ground-water body actually can expand in areal extent and can travel significant distances before it disperses.

Within the southeast region, there are several widely used methods for combating contamination of ground water after it occurs. The first step, once the problem has been discovered, is to prevent the activity from continuing to degrade water quality, in other words, to eliminate the source as quickly as possible. For example, a specific activity such as the discharge of industrial wastes into a limestone sinkhole can be ended immediately if action is brought to bear by a public agency equipped with evidence that a well supply has been rendered unfit or is threatened because of the industry's disposal method. A storage tank can be pumped dry and taken out of service if it is identified as the source of a gasoline leak that has affected ground-water quality in the area.

However, it is not always possible to immediately end some types of activities that contribute to ground-water contamination. For example, because it is a difficult and time-consuming project to find a substitute site for the dumping of refuse even though an existing site is found to be a source of ground-water contamination, some time is required before a shutdown can be effected. Additional water-quality degradation of an aquifer from septic tank wastes can be halted by the installation of collecting sewers, but again planning and implementation of such a system can be slowed drastically by economic and political considerations.

Of course, if a well supply has been affected by a pollutant, especially if the substance is toxic, the other initial step taken in combating the problem is the abandonment of the well or wells, and replacement with a new source, if available. In fact, based on the inventory of case histories in the region, the abatement procedure often ends with the abandonment of the water-supply source or the physical treatment of the water pumped in order to reduce the concentration of the pollutant to an acceptable level. This course of action is more or less typical due to the technical difficulties inherent in correcting the source of some types of ground-water contamination and the physical and economic problems involved in controlling or removing the pollutant.

Nevertheless, there are two basic approaches that have been used in the region to control the spread of or to clean up contaminated ground water. The first is containment and the second is actual removal of the pollutant.

Containment involves the use of methods to protect against the spread of degradation of water quality within the aquifer already affected, to other aquifers that might be affected, or to surface water bodies into which the contaminated ground water might discharge. It is an approach often used to protect existing ground-water and surface-water users but does not help well owners whose supplies are already damaged, nor does it fully restore water quality in the aquifer to its natural state within what might be considered a reasonable length of time.

Actual removal of the pollutants from the ground-water reservoir has been attempted at a number of locations in the southeast but is not practiced on a broad scale because of technical and economic considerations. Use of wells drilled specifically for the purpose of pumping out the contaminated fluid is the most common approach to removal. The water is then subjected to treatment on-site, discharged to a sewer or nearby surface-water body, or collected for reprocessing and reuse. Existing supply wells, to which the polluted water has migrated, have also been pumped in an attempt to reduce the volume or concentration of the pollutant. A third approach has been the construction of surface drains and ditches in order to skim the pollutant off the water table.

Generally, removal has been applied only in those cases where ground-water contamination represents a severe health or economic hazard. The presence of toxic or combustible hydrocarbon-based materials in the ground-water system is an example of a severe hazard; this is especially true in urbanized or industrialized areas where there is a good potential for loss of life and damage to property unless the greatest possible amount of the hazardous substance is removed. The discovery of a highly toxic substance in ground water, such as arsenic or mercury, which is an obvious health hazard if the contaminated fluid were to be left in the ground to perhaps migrate to a supply well or surface stream, usually precipitates quick action. Attempts also have been made to remove contaminated ground water if there is a distinct economic advantage, such as preserving a community or an industrial well vital to the water-supply system or the protection of an important aquifer.

One of the most difficult types of removal operations is that dealing with hydrocarbons. Here, the problem involves a two fluid system because of the light density and low solubility of the hydrocarbon. The pollutant floats and migrates on top of the water table. Drawing down water levels and inducing the fluid to migrate toward a pumping well will trap only a portion of the hydrocarbon. Ultimately, as the hydrocarbon lens thins, less and less of the substance is removed. Thus, in addition to pumping wells, use has been made of ditches and trenches to skim oil off the water table, biological processes to break down gasoline in the ground, and water-flooding techniques to drive solvents and other hydrocarbons to central collection points, all with limited success. Another factor which cannot be ignored is that even when a pollutant can be successfully removed from an aquifer, the time period involved and the quantity of water pumped are usually considerable. Also, after the contaminant and its accompanying large volume of water is removed there still remains the major problem of converting this hazardous mixture to a harmless state. Sometimes successful treatment can be accomplished by merely diluting the material with large quantities of clean water. In some cases, treatment of the contaminant-water mixture in an industrial or municipal liquid waste or sewage treatment facility is possible. However, with some contaminants such as chlorinated hydrocarbons, cyanide and similar poisonous materials, dilution-related treatment methods are not always effective so that much more complex and costly processes of treatment or neutralization must be employed.

Any discussion of the problems associated with the control and correction of existing ground-water contamination problems would not be complete without consideration of the high costs involved. Although very little information was obtained on cost estimates for clean-up operations, it is known that some plans had to be abandoned because of economic considerations. In addition, some operations are still in progress so that final cost figures are not available.

Health Hazards and Other Effects of Contamination

In order to fully understand the health hazards and other adverse effects of ground-water contamination, it is necessary to review the principles governing the movement within the ground-water system of a water body containing pollutants. Most problems of contamination begin when an objectionable fluid arrives at the water table. The fluid may have leaked out of unlined municipal or industrial waste lagoons, septic tank tile fields, or ruptured sewers, pipelines and storage tanks. On the other hand, the contamination could have been transported to the ground-water reservoir with precipitation, recharge from solid waste landfills, liquid waste land disposal sites, industrial plant grounds, urban and rural roads, animal feed stations and farm fields, mining spoil disposal lands, and by ground-water development. Figure 21 shows schematically the many different ways a contaminant can enter the ground-water system through man's activities.

Once a contaminated liquid reaches the ground-water reservoir, it moves downgradient through the water-bearing material from its point of entry to some lower pressure discharge point. Its rate of movement depends largely upon the permeability of the earth materials and the hydraulic gradient in the ground-water system. For example, in unconsolidated fine-grained sediments such as clay, ground water may move less than 3 m (10 ft) per year under natural geohydrologic conditions. In sandy aquifers the movement is rarely more than 152 m (500 ft) per year, and even in very permeable gravel units the rate of travel probably would not exceed 762 m (2,500 ft) per year. On the other hand, the distance and rate of travel can be considerably greater if the contaminated fluid moves through fracture zones or solution cavities of rock formations. Where pumping from wells has lowered ground-water levels in an aquifer, the rate and direction of travel are also affected, and the pollutant can move more quickly toward the center of pumping.

Other factors important to the occurrence and movement of contaminated ground water are the various processes that can affect the concentration of the pollutant, such as adsorption

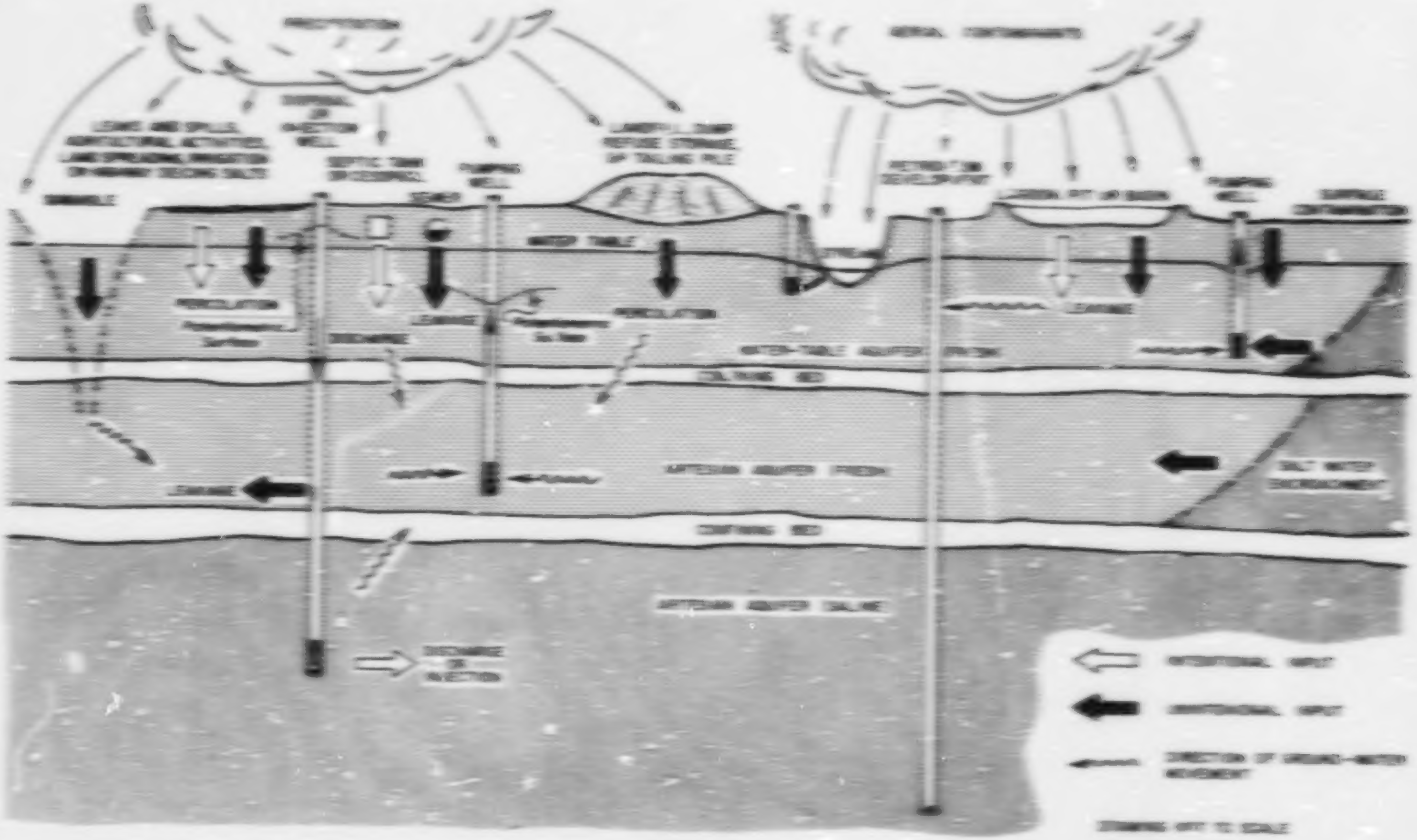

PRECIPITATION
AERIAL CONTAMINANTS
LEAKS AND SPILLS, AGRICULTURAL ACTIVITIES, LAND SPREADING, IRRIGATION OR HIGHWAY DEICING SALTS
DISPOSAL OR INJECTION WELL
SEPTIC TANK DISCHARGE
PUMPING WELL
SEWER
LANDFILL, DUMP, REFUSE STORAGE OR TAILING PILE
PETROLEUM DEVELOPMENT
LAGOON PIT OR BASIN
PUMPING WELL
SURFACE CONTAMINATION
SINKHOLE
WATER TABLE
PERCOLATION
LEAKAGE
DISCHARGE
PERCOLATION
LEAKAGE
WATER-TABLE AQUIFER FRESH
CONFINING BED
ARTESIAN AQUIFER FRESH
LEAKAGE
SALT WATER ENCROACHMENT
CONFINING BED
ARTESIAN AQUIFER SALINE
DISCHARGE OR INJECTION
INTENTIONAL INPUT
UNINTENTIONAL INPUT
DIRECTION OF GROUND-WATER MOVEMENT
DRAWING NOT TO SCALE

Figure 21. Schematic drawing of routes for ground-water contamination.

by the materials through which it passes, its density with respect to that of natural ground water, and the manner in which it spreads out or disperses as it travels. Adsorption or physiochemical forces can remove pollutants from solution and concentrate them on soil, clay, or fine-grained sand materials. Ion exchange and precipitation also can alter the character of the contaminant. Differences in density may cause a contaminant to travel in a direction somewhat different from that of the natural ground water. For example, gasoline will tend to float on the water table, even where there is a strong downward component of flow in the aquifer system. Dense fluids introduced into a fresh-water aquifer may tend to sink to the bottom of the aquifer under the influence of gravity before moving horizontally downgradient from their initial point of entry.

Polluted water moving through an aquifer generally takes on the form of a bulb or plume, extending along the flow path from the source of the pollution to a point where it is either attenuated within the aquifer or is discharged to a well or a surface-water body such as a river, a lake, or the sea. Although dispersal in the direction of flow tends to reduce the concentration of a pollutant, the fluid normally does not fan out, and dispersal across the direction of flow is considerably less than that taking place during the distance traveled. Figures 22 and 23 illustrate this effect in an unconsolidated sand and gravel aquifer. Movement of a contaminated fluid in fractures of a rock aquifer is shown in Figures 24 and 25. In this latter case, dispersion is very slight and the fracture pattern controls the shape and areal extent of the plume. Figure 26 illustrates the type of plume associated with a light-density fluid such as oil or gasoline.

Figure 27 shows how temporary flooding around a well can cause ground-water contamination. Downward flow of polluted surface water takes place around the well casing because of improper placement or lack of a seal at ground surface.

Figure 28 shows how contaminants introduced into a disposal well or entering the ground from a surface water body can move into a pumping well. Because the well is a convergence point for ground water, it acts as a collection mechanism.

Figure 29 illustrates how interaquifer transfer of water may take place. The potential degradation of an aquifer containing good quality water by upward movement of mineralized water from an underlying aquifer occurs because pumping from wells reverses the natural hydraulic gradient, indicated by the change in the relative position of the two water levels.

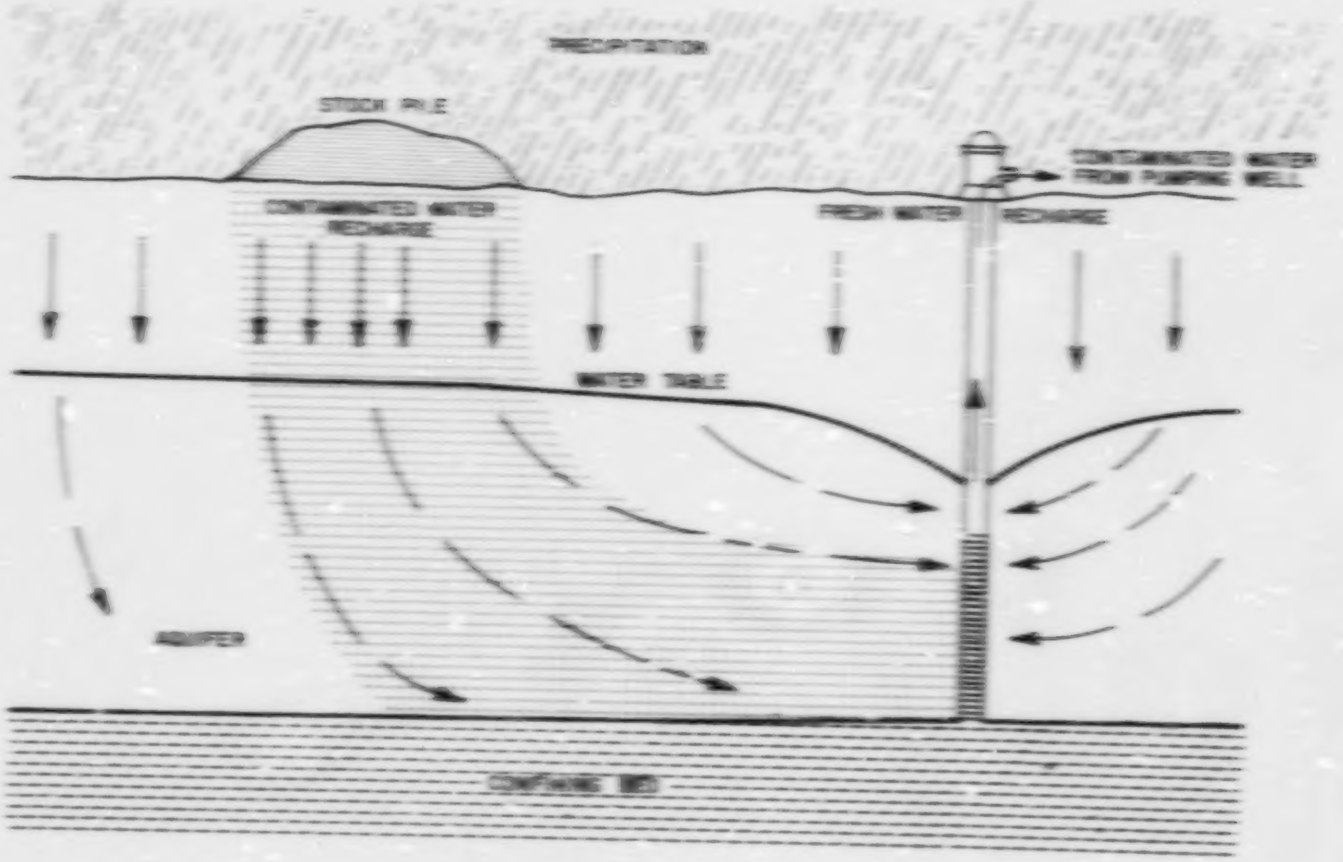

PRECIPITATION
STOCK PILE
CONTAMINATED WATER FROM PUMPING WELL
CONTAMINATED WATER RECHARGE
FRESH WATER RECHARGE
WATER TABLE
AQUIFER
CONFINING BED

Figure 22. Flow pattern showing downward leaching of pollutants from a stockpile and movement toward a pumped well.3)

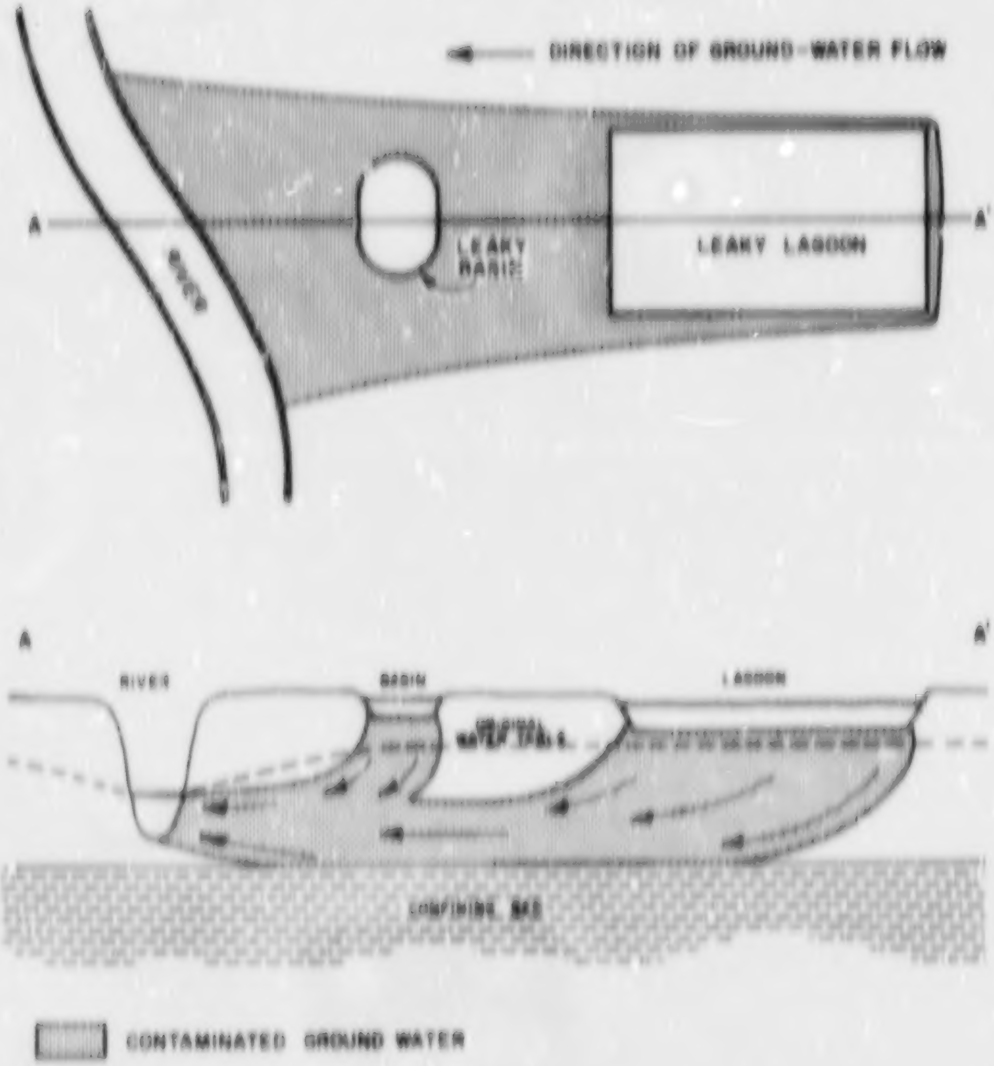

DIRECTION OF GROUND-WATER FLOW
A
A'
RIVER
LEAKY BASIN
LEAKY LAGOON
A
A'
RIVER
BASIN
LAGOON
ORIGINAL WATER TABLE
CONFINING BED
CONTAMINATED GROUND WATER

Figure 23. Contaminated ground water as caused by leakage from a lagoon and a basin into a water-table aquifer discharging into a river.

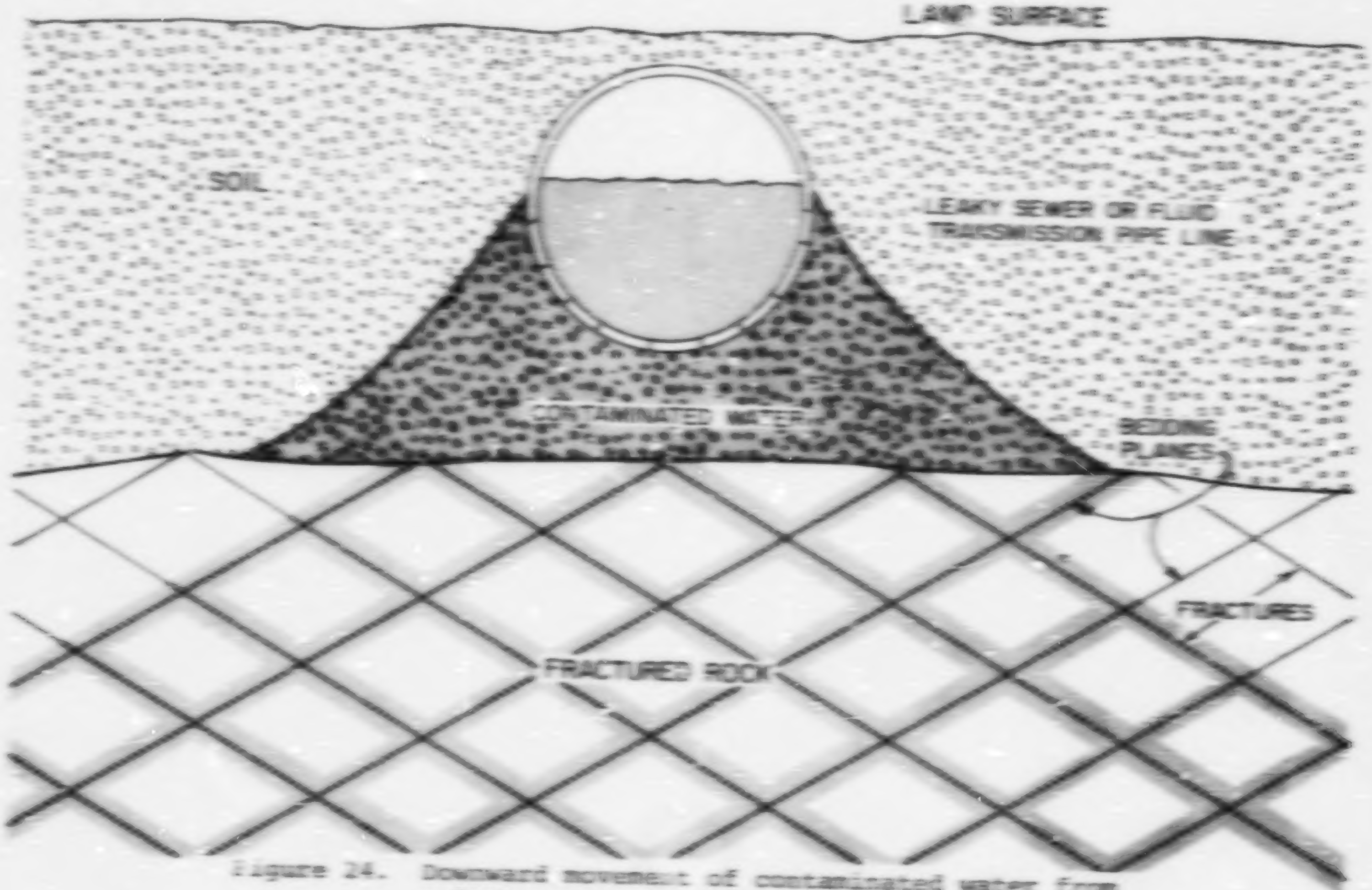

LAND SURFACE
SOIL
LEAKY SEWER OR FLUID TRANSMISSION PIPE LINE
CONTAMINATED WATER
BEDDING PLANES
FRACTURES
FRACTURED ROCK

Figure 24. Downward movement of contaminated water from a leaky sewer into the bedding planes and fractures of a rock aquifer.

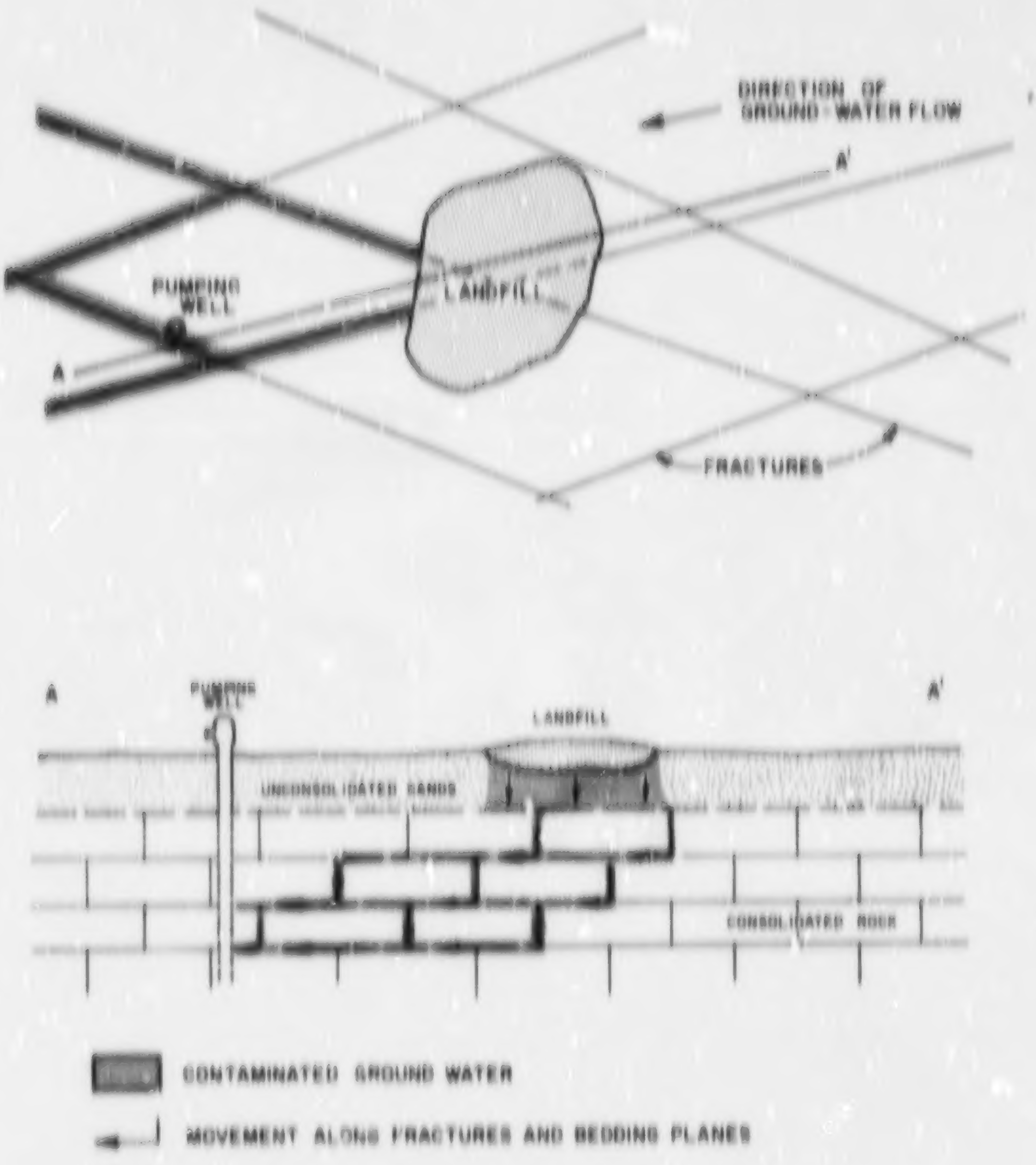

DIRECTION OF GROUND-WATER FLOW
A'
PUMPING WELL
LANDFILL
A
FRACTURES
A
PUMPING WELL
LANDFILL
A'
UNCONSOLIDATED SANDS
CONSOLIDATED ROCK
CONTAMINATED GROUND WATER
MOVEMENT ALONG FRACTURES AND BEDDING PLANES

Figure 25. Contaminated ground water in bedding planes and fractures in a rock aquifer, caused by leachate from a landfill.

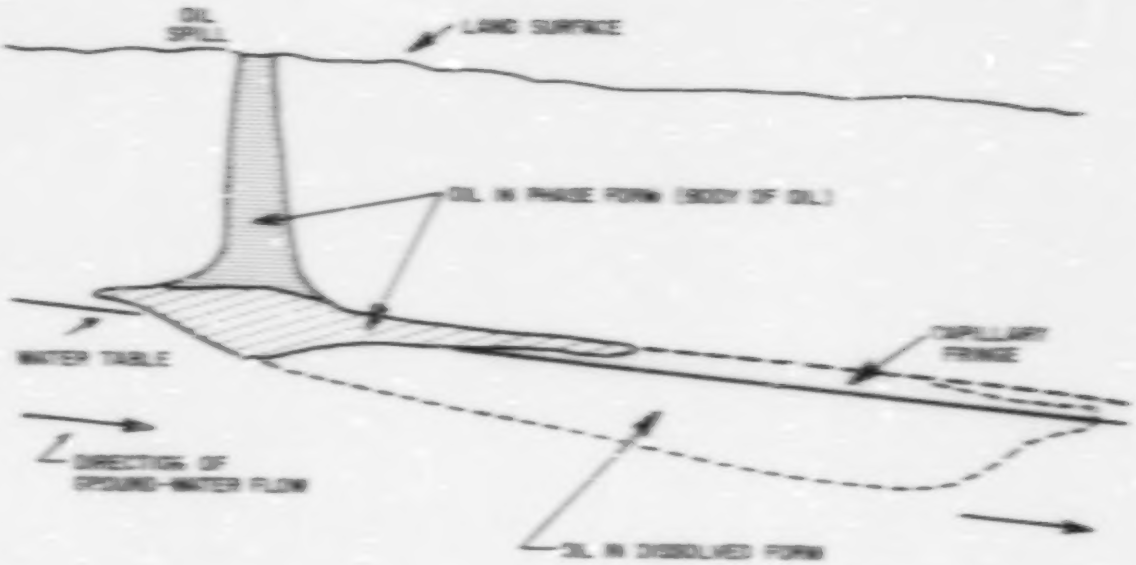

OIL SPILL
LAND SURFACE
OIL IN PHASE FORM (BODY OF OIL)
CAPILLARY FRINGE
WATER TABLE
DIRECTION OF GROUND-WATER FLOW
OIL IN DISSOLVED FORM

Figure 26. Movement of light-density fluid in the ground-water system. Contamination caused by a spill of hydrocarbons.4)

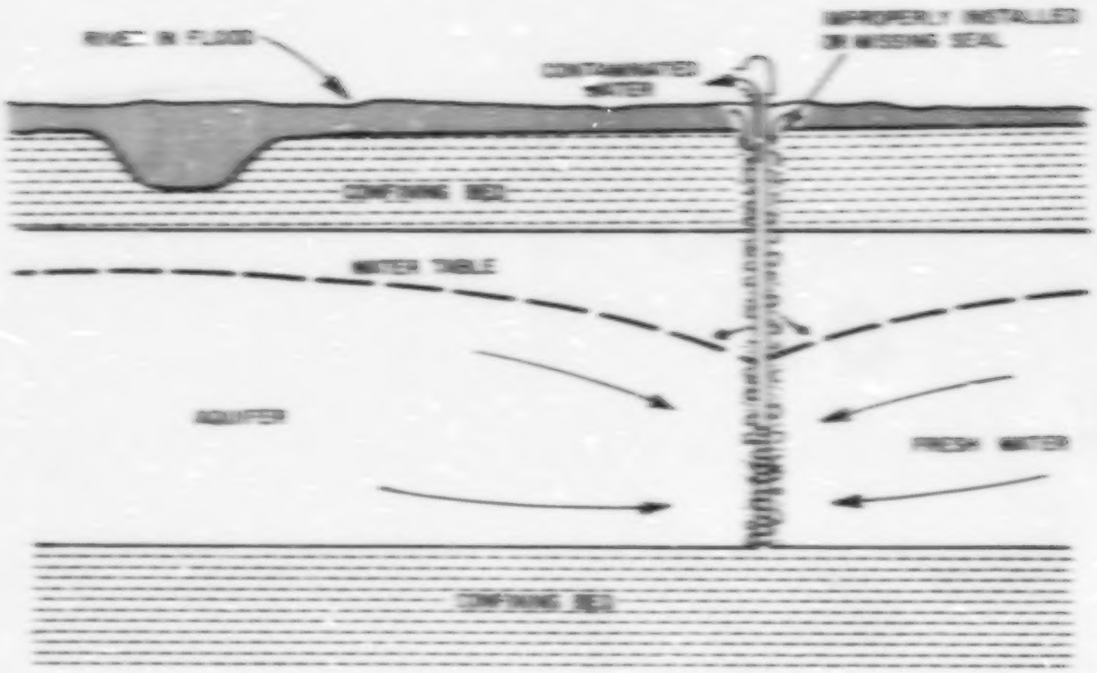

RIVER IN FLOOD
CONTAMINATED WATER
IMPROPERLY INSTALLED OR MISSING SEAL
CONFINING BED
WATER TABLE
AQUIFER
FRESH WATER
CONFINING BED

Figure 27. Diagram showing flood water entering a well through a missing or improperly installed seal on a well.3)

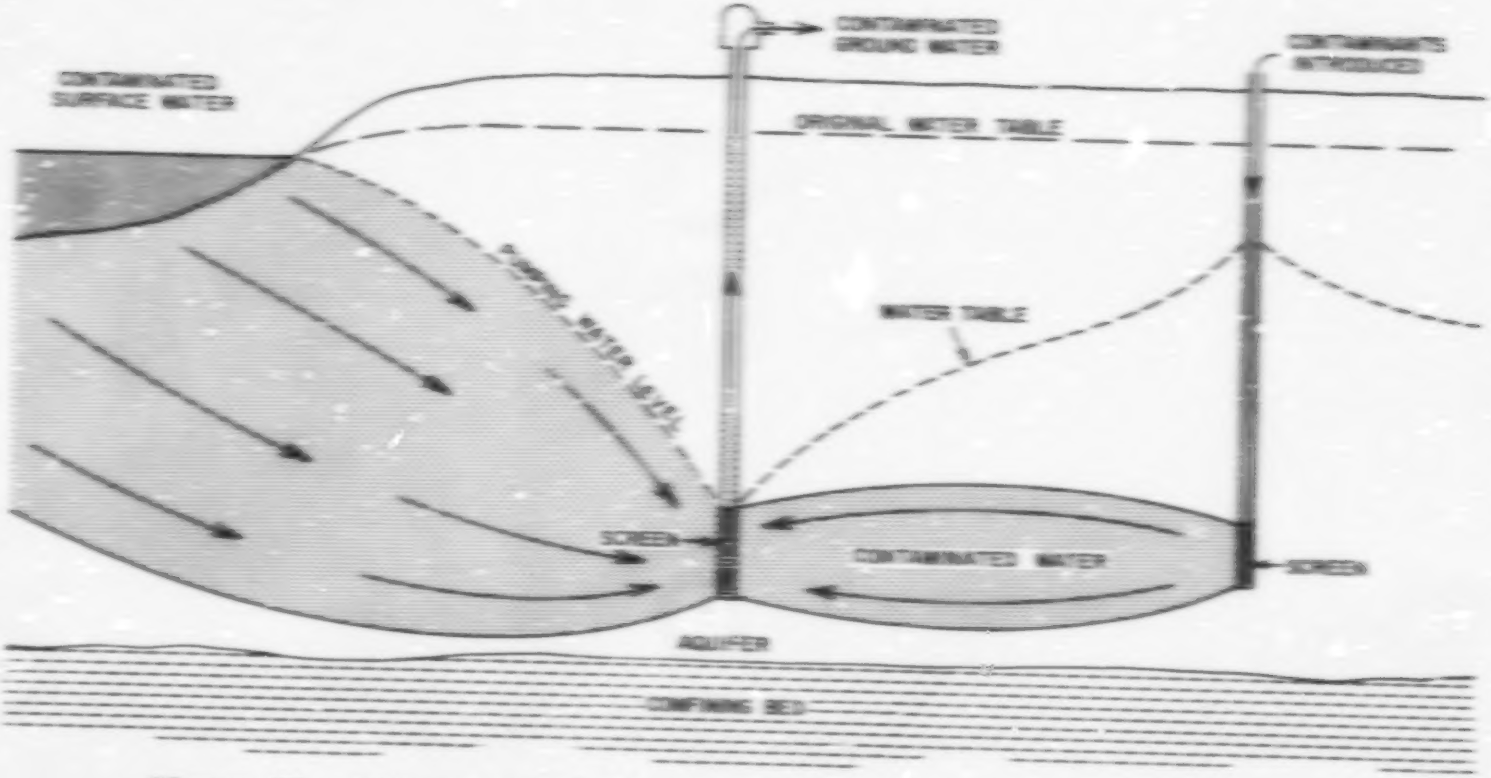
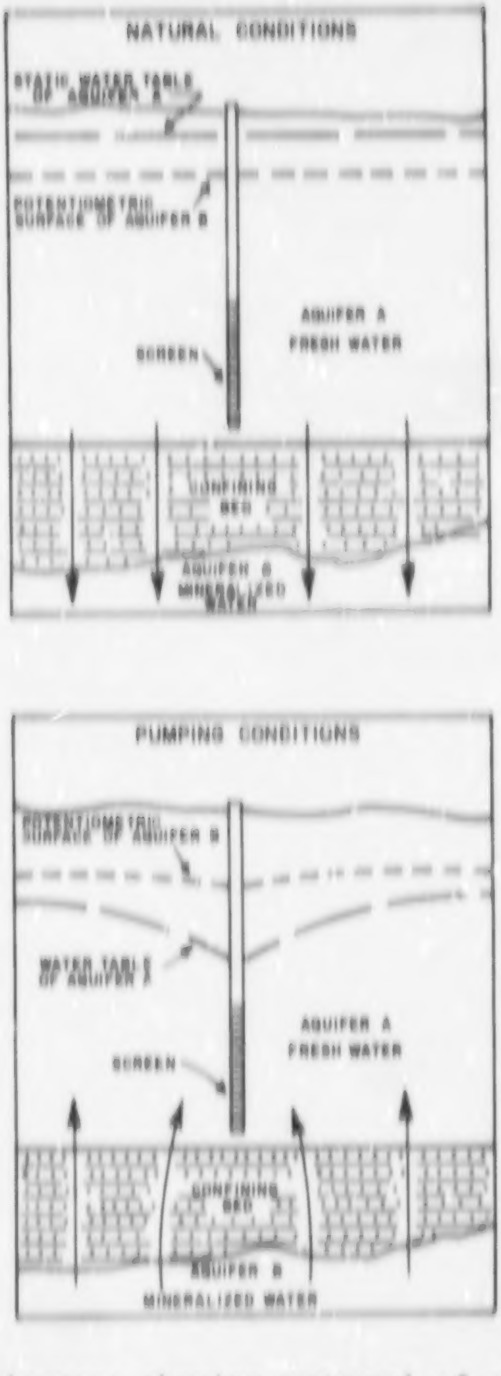

CONTAMINATED SURFACE WATER
CONTAMINATED GROUND WATER
CONTAMINANTS INTRODUCED
ORIGINAL WATER TABLE
PUMPING WATER LEVEL
WATER TABLE
SCREEN
CONTAMINATED WATER
SCREEN
AQUIFER
CONFINING BED

Figure 28. Diagram showing movement of contaminants from a recharge or drainage well and surface water body to a nearby pumping well.



NATURAL CONDITIONS
STATIC WATER TABLE OF AQUIFER A
POTENTIOMETRIC SURFACE OF AQUIFER B
AQUIFER A
FRESH WATER
SCREEN
CONFINING BED
AQUIFER B
MINERALIZED WATER
PUMPING CONDITIONS
POTENTIOMETRIC SURFACE OF AQUIFER B
WATER TABLE OF AQUIFER A
AQUIFER A
FRESH WATER
SCREEN
CONFINING BED
AQUIFER B
MINERALIZED WATER

Figure 29. Diagrams showing reversal of aquifer leakage by pumping.7)

Although the role that ground-water contamination plays in waterborne-disease outbreaks in this particular region is obscure, national surveys have shown it to be an important factor. One problem is that almost all privately supplied homes, some small community systems, and even some larger public utilities are supplied with insufficiently treated or even untreated ground water. Therefore, the user may be exposed to bacteria and virus which have entered the well because of poor well construction, improper location with respect to septic tanks, or flooding of the land surface with polluted surface water containing sewage effluent.

Tables 22 and 23 show the results of an inventory in the United States of water-borne disease outbreaks related to ground-water sources for the period 1946-70. The more than 47,000 cases are significant, especially in view of the fact that most cases of illness related to contaminated ground water probably are not reported because they are isolated cases, or no death has occurred, or the source of the disease was not suspected or investigated.

The Relationship of Ground Water to Surface Water

One often overlooked aspect of ground-water contamination in the humid Southeast is the close relationship between ground-water and surface-water quality. Most programs for cleaning up streams neglect to take into account the fact that ground-water discharge represents a major portion of flow in rivers and that during dry times of the year stream flow is often 100 percent ground-water discharge. Because stream quality criteria are based on low flow quantities and quality, it is essential to maintain the quality of ground water in order to protect surface water.

Great effort is being directed toward improving the quality of surface water by seeking out sources of pollution discharging directly into streams and by requiring treatment or some other means for upgrading waste-water quality. However, few investigations include an evaluation of the quality of ground water entering a particular stream, or an inventory of potential sources of ground-water contamination that are already or might ultimately discharge into a surface-water body.

Numerous case histories have been uncovered in this investigation where contamination of ground water from a point source has significantly affected surface-water quality, at least in the general vicinity of the area into which the plume of the contaminated ground water is discharging. These include problems of seepage related to lagoons, pits, basins, mine drainage, spills, and landfills.

Table 21. INCIDENCE OF WATERBORNE DISEASE IN THE UNITED STATES FOR UNTREATED CONTAMINATED GROUND WATER.[51]

	Private		Public		All Systems	
Cause	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases
Improper construction of well or spring						
Surface contamination nearby	21	640	1	2,500	22	3,140
Overflow or seepage of sewage	49	2,779	4	531	53	3,310
Seepage from abandoned well	1	50	-	—	1	50
Source of contamination not determined	8	235	1	400	9	635
Flooding	4	66	3	4,400	7	4,466
Contamination through creviced limestone or fissured rock	10	555	1	70	11	625
Chemical or pesticide contamination	4	17	-	—	4	17
Data insufficient to classify	46	2,001	3	16,350	49	18,351
Total:	143	6,343	13	24,351	156	30,594

Table 21. INCIDENCE OF WATERBORNE DISEASE IN THE UNITED STATES, 1946-70, GROUND WATER (CHLORINATED ONLY): TREATMENT OVERWHELMED DUE TO SOURCE CONTAMINATION.[53]

Cause	Private Outbreaks	Private Cases	Public Outbreaks	Public Cases	All Systems Outbreaks	All Systems Cases
Overflow or seepage of sewage	-	-	3	16,273	3	16,273
Flooding	-	-	1	600	1	600
Contamination of raw-water transmission line or suction pipe	1	31	-	-	1	31
Total	1	31	4	16,873	5	16,904

The Problem of Monitoring

Monitoring ground-water contamination and providing a means for adequate warning against use of waters that may be harmful are especially difficult problems, owing to:

1. The complex nature of aquifer systems and patterns of movement of ground water.

2. The large number of individual wells and springs being used.

3. The great variety of potential sources of contamination, and their relative abundance in the Southeast.

4. The lack of information on the quantities and kinds of chemical compounds being discharged to the air, soil, and water.

5. The scanty knowledge of the biological, chemical and physical reactions taking place among the contaminants, the soil and rock materials, and the native ground water.

The movement of contaminants through aquifer systems, as described previously, is dependent upon local and regional ground-water flow patterns, which are not discernible through a casual visual inspection. If a load of chemical waste is dumped into the Mississippi River, for example, it is expected to move downstream. Furthermore, if the river is being polluted with high counts of coliform bacteria, a sample dipped from almost any portion of the stream will give some indication of the pollution. Not so with ground water, where "downstream" may be in any direction, not necessarily related to the surface topography at any particular location. Also, polluted fluids do not always move with the main body of ground water. They can float on the water table or sink toward the bottom of the aquifer, and can move at a different rate than the ground water.

Thus, determination of the direction of flow and areal extent of a contaminated ground-water body often can be determined only by a rather detailed and costly program of test drilling and investigations of water-level changes and differences in water quality. Even determining the configuration of the water table may not be adequate for defining the problem, because this only indicates the horizontal direction of flow and gives no indication of how deeply contaminated fluid may descend along its path to a point of discharge, or when it will arrive at that point.

For example, under some conditions, a drop of water may travel at fairly shallow depths from the place where it reaches the water table to the place where it leaves the ground-water system. Elsewhere, it may descend rather steeply to invade aquifers many hundreds of feet below the water table, and may move through those aquifers in a direction quite different from that followed by water in the shallow beds. Therefore, a proper evaluation of ground-water flow involves a knowledge of what is taking place in the vertical dimension as well as in the horizontal.

Figure 30 illustrates this principle. The diagrams in the figure are hypothetical but are based on detailed studies of the hydrology of several solid waste landfills. Figure 30A is a water-table map showing that the highest point on the water table underlies the landfill area. According to one basic law of ground-water flow, the horizontal direction of movement of any drop of ground water in an unconfined aquifer is at right angles to the water-table contours. Thus, a drop starting at point "B", for example, will ultimately discharge into the adjoining marsh whereas a drop introduced at point "A" will eventually flow in an opposite direction to the adjacent stream. Figure 30B, which is a cross section through the hypothetical landfill along line X-X', shows, by means of arrows, the vertical pattern of flow. A drop of contaminated fluid reaching the water table at point "A" would penetrate quite deeply into the underlying sediments before being discharged into the river. As an example, abnormally high levels of iron, chloride, and hardness have been found in observation wells screened more than 30.5 m (100 ft) below the water table beneath a landfill, indicating penetration to this depth of ground water contaminated by contact with the refuse.

Stratification of sediments within a sand and gravel aquifer can locally modify the movement of ground water and distort the overall pattern of flow. Unfortunately, this factor all too often is ignored in many monitoring systems. In some land disposal sites, for example, only the lower more permeable parts of the unconsolidated earth material above bedrock are tapped by monitoring wells, even though overlying water-bearing zones are known to be present. Under such conditions, as illustrated in Figure 31, a major portion of ground-water pollution derived from the disposal sites may flow undetected through these overlying beds to some nearby natural or man-made drainage course. A similar type of situation can also occur if too few monitoring wells are installed or if the wells tap only the uppermost part of the zone of saturation.

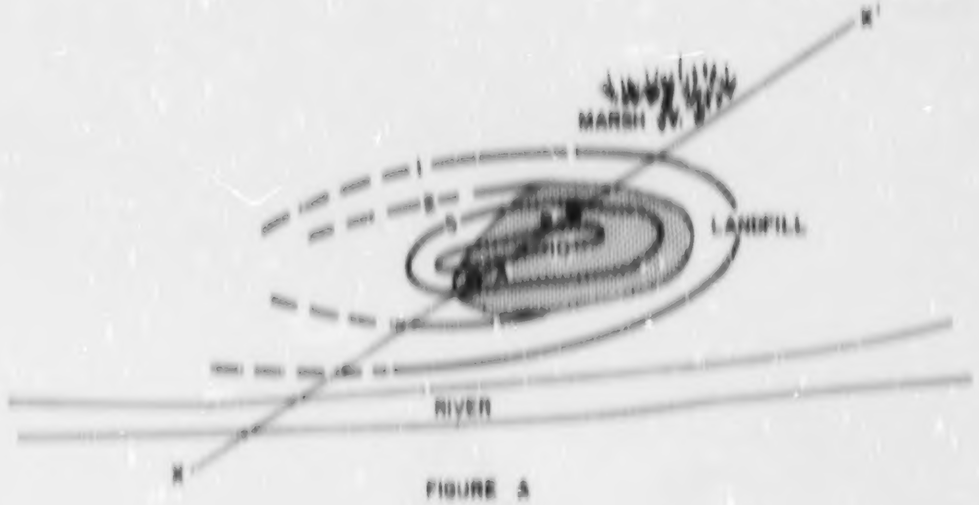

X'
MARSH
LANDFILL
10
5
1
RIVER
X

FIGURE A

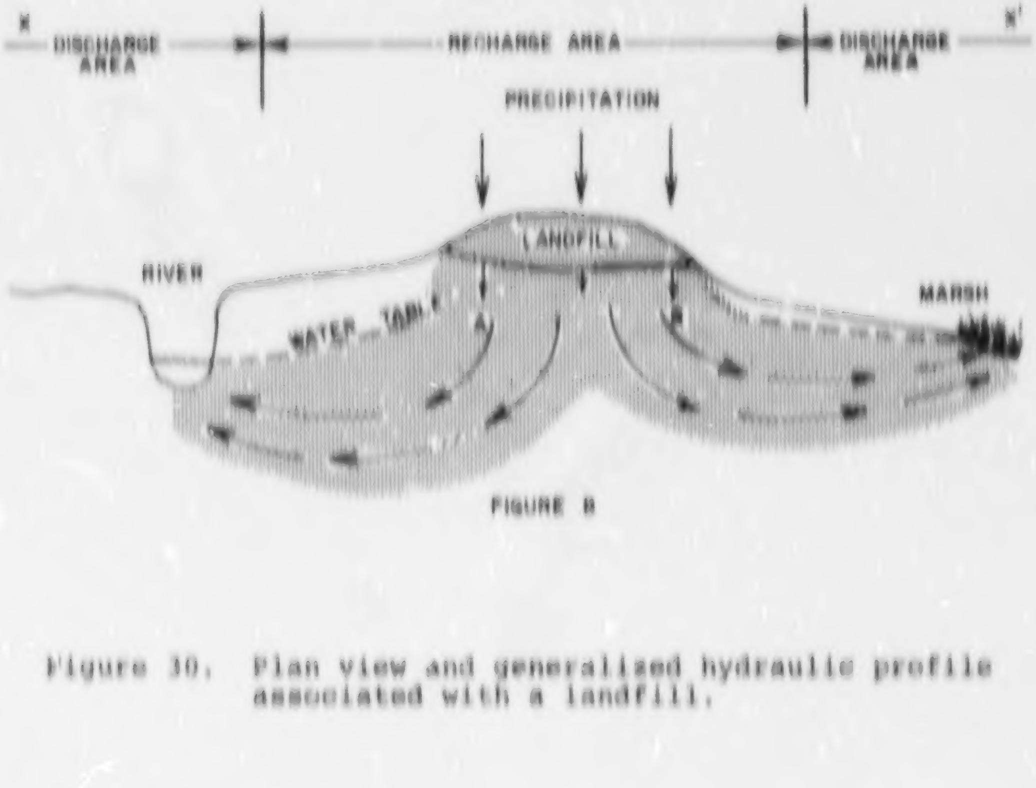

X
DISCHARGE AREA
RECHARGE AREA
DISCHARGE AREA
X'
PRECIPITATION
LANDFILL
RIVER
WATER TABLE
MARSH

FIGURE B

Figure 30. Plan view and generalized hydraulic profile associated with a landfill.

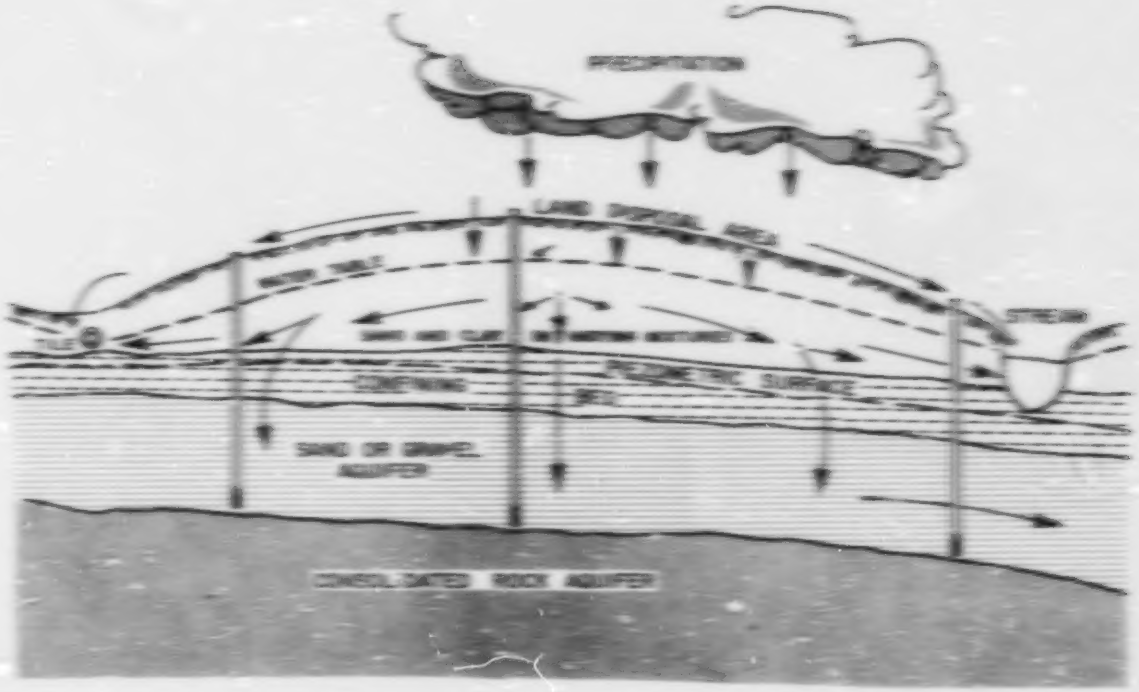

PRECIPITATION
LAND DISPOSAL AREA
WATER TABLE
TILE
STREAM
SAND AND CLAY
CONFINING BED
PIEZOMETRIC SURFACE
SAND OR GRAVEL AQUIFER
CONSOLIDATED ROCK AQUIFER

Figure 31. Diagram showing an ineffectual ground-water monitoring program using only deep wells.

Thus, locating pollutants in the ground-water system is a complicated matter. Even after contamination is indicated, defining the problem calls for use of all the various techniques available to the investigator.

The second problem with regard to monitoring is the difficulty of keeping track of the long-term quality of water withdrawn from the large number of public supply, industrial, and domestic wells in the region. In none of the seven states of the project area are accurate figures available on the number of wells drilled each year, how many are in use, or what proportion are abandoned. Even in those states where permits are required for new well construction, many wells are installed without permits or do not come under the definitions of the permitting regulations. Each year a tremendous number of new wells are constructed, but analyses of water are made for only a relatively small percentage of them. Exceptions to this, of course, are public water-supply wells which invariably must be approved by some type of health authority before they are put into service. Generally, domestic wells and those used by industry for drinking-water purposes do not normally fall within the authority of public health agencies.

Many state and local agencies provide free analyses for selected chemical constituents and bacteria in water from private sources when the sample is brought in on a voluntary basis. Many of the state laboratories are sorely taxed trying to keep up with this activity. Nevertheless, only a relatively small percentage of the wells drilled are sampled initially, and even fewer are sampled on a periodic basis. Of equal concern in this regard is the fact that many of the most hazardous contaminants are difficult and costly to analyze by presently available methods and equipment and not identified in typically prescribed analyses programs, an omission that creates continuous uncertainty concerning their possible existence even in those few well-water supplies that are actually sampled and analysed.

In some states and local areas, there has been a growing trend toward requiring analyses of new private well-water supplies and certification by a health agency before the well can be put into service in the home or factory. This trend undoubtedly will continue but there still will be a need to sample wells that have been in service for many years, to conduct periodic analyses of water from new wells, and to locate the large number of unreported wells installed each year in the region.

Table 24 shows that the total number of on-site water supplies in the study area in 1970 was in excess of 2.7 million. Continuously monitoring such a large number of facilities on a periodic basis is practically an impossibility.

Another problem in monitoring is the great variety of inorganic salts, acids or bases, synthetic organics, flammables and other compounds produced or used each year in the Southeast. Much of this material is toxic and finds its way into industrial waste streams. It has been pointed out that of 496 organic chemicals considered likely to be found in waste water, only 66 have been positively identified.[7] Hazardous substances such as arsenic, cadmium, chromium, chlorinated hydrocarbons, cyanides, lead, mercury, copper, and zinc are widely used or produced in many industrial activities including metallurgy; paint, rubber, and paper manufacturing; and the production of batteries, pharmaceuticals, and textiles.

Unfortunately, many toxic substances are not included in normal analyses conducted on water-supply sources. In fact, in the seven southeast states, analyses for some of the hazardous elements such as barium, selenium, and silver, included in the U. S. Public Health Service Drinking Water Standards, 1962, are not usually required for a ground-water source to be approved, nor are they often included in routine analyses unless contamination is suspected.[8]

Interviews with public health personnel in the region did indicate that more effort is being made to determine the possible presence of toxic substances, and that there is an overall trend toward more detailed analyses of drinking water. However, again this is difficult to accomplish due to limitations of budget, staff, and laboratory facilities.

It is interesting to note that a large portion of the ground-water contamination case histories inventoried in this investigation came to the attention of authorities because of complaints of taste and odor, noticeable effects on surface waters or vegetation, or through the investigation of an accident such as a ruptured storage tank or a spill of hazardous material. Few were uncovered in the course of routine analysis of the water itself. Where hazardous substances were present, for example, in those cases involving high concentrations of arsenic, hexavalent chromium, cyanide, or lead, it was a change in the non-toxic chloride content, or hardness, that led to more complete analyses of the water from the affected source. Only after the more detailed testing was the presence of the toxic substance determined.

Table 24. NUMBER OF ON-SITE WATER SUPPLIES BY STATE FOR 1970.[6]

State	On-Site Supply
Alabama	339,305
Florida	390,423
Georgia	351,318
Mississippi	246,144
North Carolina	732,273
South Carolina	289,771
Virginia	418,948
Total	2,768,182

Information was obtained from selected well drillers in the seven-state study area pertaining to the most common reason for well replacement in a given year. Table 25 shows the most common source of contamination which required water-supply well replacement. For the most part, the replaced wells were used for individual domestic supply and do not show the ground-water contamination prevalent around industrial complexes. However, a few probably involved industrial and municipal supplies.

Summary

The various factors discussed above should indicate the cause for concern regarding ground-water contamination and the need for more research, control, and education to help prevent new occurrences and to aid in correcting existing problems. This investigation revealed the fortunate circumstance that there are dedicated technicians on different levels of government in each of the states working toward educating the public on the importance of protecting ground-water quality, in addition to developing guidelines and manuals to prevent practices that might adversely affect underground water sources. However, activities involved in the protection and monitoring of ground-water quality, with a few notable exceptions that will be discussed later in this report, are too splintered among various agencies to be effective. In addition, the agencies are hindered by lack of sufficient budget to staff properly and to carry out the functions necessary for ground-water management programs to be successful.

In the following portions of this section, key sources of contamination will be explored in greater detail. By this means, it is hoped that the principal problem areas, which require the greatest effort, can be illustrated. A review of case histories on ground-water quality degradation provides the best means for understanding the nature and possible extent of the problem in the Southeast. In this regard, selected instances of contamination are tabulated. Where possible, locations and references are provided for each of the cases included. However, where future litigation may be involved, for example, and the data shown do not appear in the literature, the location and reference may not be listed in order to respect the confidential nature of the information.

PRINCIPAL SOURCES OF GROUND-WATER CONTAMINATION

Natural ground-water quality in the southeast region generally can be described as good to excellent, and only in

Table 25. MOST COMMON SOURCES[a] OF CONTAMINATION REQUIRING WATER-SUPPLY WELL REPLACEMENT AS REPORTED BY SELECTED WELL DRILLERS IN THE SOUTHEAST.[9]

Reason	Number of wells replaced	Number of drillers
Leaks and spills[b]	57	16
Septic tanks	48	9
Salt-water encroachment	20	5
Mining activities	9	2
Feedlots (all animals)	8	4
Pesticides	4	2
Fertilizers	3	1
Surface impoundments	2	2
Landfills	1	1
High water from river	1	1

a) Shallow wells and poor construction methods were reported as problems by ten drillers. Additionally, two drillers reported having to drill to deeper horizons because of citrus pulp disposed of in wells and storm runoff and raw sewage disposed of in drainage wells.

b) 55 of these are hydrocarbon products.

very localized parts of the region are there natural contaminants present that pose a potential health hazard. On the other hand, man's activities and the many thousands of tons of waste materials he produces each year are causing an ever-increasing number of ground-water contamination problems which are now in need of attention, solution and control if optimum protection of the ground-water resources in this region is to be assured in the future.

Some idea of the wide variety of potential sources of ground-water pollution can be gained from the compilation given in Table 26, which is based on an analysis of actual reported cases of ground-water contamination inventoried during this investigation. Representative examples of the various categories listed were obtained from public agencies involved in health and environmental matters, from well-drilling contractors, from private organizations such as consulting firms and business associations, and from literature sources. It can be seen that many activities of man can lead to degradation of ground-water quality. Monitoring of the potential source, either by means of accurate measurement of losses of fluid and soluble material to the ground-water system or through the installation of enough wells for periodic water-quality sampling, is an almost insurmountable task. Even inventorying the location of potential sources of contamination is a major problem for regulatory agencies.

Although no list could contain all causes of subsurface contamination, Table 26 does include the key sources, and an attempt has been made to rank them in terms of their relative degree of actual or potential harm to public health. If considered on this basis, it follows that contamination derived from poisonous substances must be assigned a higher priority of importance than actual or possible water-quality degradation resulting from objectionable yet relatively harmless ingredients such as chlorides and sulfates. By the same token, the relative size of area affected by any given contaminant and the probable future trend in its rate of new occurrences also were major considerations in this listing. The estimated values in Table 26 are based on an evaluation of such factors as awareness of toxicity, volume, size of area affected, particular source of contamination, the predicted degree of future increase of new sources, and the level of technology and staffing available to prevent future problems.

The ranking presented in the table considers the entire southeast study area and as such the ranking of any particular source of contamination will differ on a state-by-state basis. For example, those states without petroleum

Table 26. RANKING OF THE PRINCIPAL SOURCES OF GROUND-WATER CONTAMINATION AND THEIR RELATIVE IMPACT IN THE SOUTHEAST UNITED STATES.

Source of Ground-Water Contamination	Toxicity Ranking	Volume Ranking	Size of Area Affected[a)]	Estimated Future Trend Rate of New Occurrences[b)]	Totals of all Columns
SURFACE IMPOUNDMENTS	1	3	3	1	8
LANDFILLS (urban & industrial)	2	6	3	1	12
UNDERGROUND STORAGE OF WASTE FLUIDS & SURPLUS WATER	3	7	3	1	14
LEAKS & SPILLS	4	4	3	1	11
AGRICULTURAL ACTIVITIES	5	5	2	2	14
MINING ACTIVITIES	6	9	2	2	19
SEPTIC TANKS	7	1	2	1	11
LAND DISPOSAL OF WASTE WATERS	8	13	3	1	25
MISCELLANEOUS SOURCES	9	11	3	2	25
GROUND-WATER DEVELOPMENT	10	2	1	1	14
PETROLEUM DEVEL-OPMENT ACTIVITIES	11	8	2	2	23
NATURAL BODIES OF SURFACE WATER	12	10	3	2	27
HIGHWAY DEICING	13	12	3	2	30

a) 1=Regional
2=Point source but can be regional in nature due to high density of individual occurrences
3=Can affect adjacent properties

b) 1=Increase
2=No significant change

development activities can essentially eliminate this source of contamination from any listing generated on a state basis. The totals shown in the last column are an attempt to assign priorities to the principal sources, using the four separate criteria. The lower the total derived, the higher the priority.

When considered on an individual state level, the number of columns could be expanded to include such factors as: economic considerations, method of abatement and removal, alternate plans, technical feasibility, impact of proposed plan on environment, time factors to implement and complete the plan, sufficient and capable staff to supervise the program and follow-up, and impact of continuing with the situation as is relative to a time period. In other words, the use of a ranking system can be beneficial on local and state levels to rank sources of contamination and initiate programs of abatement and removal. Without such priorities, the method of attack will continue to be more or less disorganized and geared mainly to emergency situations.

From Table 26 it is apparent that the wastes man generates and eventually must throw away in a solid or liquid state pose a very serious threat to ground-water quality throughout the southeast region. This is readily understandable when it is considered that practically all of the waste produced is eventually dumped somewhere--on or beneath the land surface or into some nearby stream or ocean. Land storage-attenuation and water dilution generally are the most common disposal-treatment methods employed because they are the most economically attractive. For example, costs of land disposal now range from 4 to 50 times less than costs of other available processing or treatment methods, depending upon the nature of the waste to be treated. In addition to this cost incentive, the waste originator is being forced to utilize land disposal by current air and surface water pollution protection laws which prohibit or seriously restrict burning of many combustible solid and liquid waste streams or water dilution treatment of a host of others that are inorganic in nature and not readily treatable by any other means. Also, economic and population growth and new methods of manufacture, packaging and marketing have resulted in the production of an ever-increasing amount of refuse which must be eventually discarded. The waste disposal problem is made even more complex by other pollution control regulations now being developed and enforced which restrict land disposal to those methods and those disposal sites that are least likely to cause serious adverse environmental effects.

The magnitude of the problem is evident when it is considered that the nation produced more than 3.9 billion tonnes (4.36 billion tons) of solid wastes in 1969 and about 79.5 trillion litres (21 trillion gallons) of waste water each year during the period 1963-1970.[2,6,10] Of this amount, only about 8.3 percent or 327 million tonnes (360 million tons) of the solid waste is derived from residential, commercial, institutional and industrial sources; the remainder is fairly evenly distributed between agricultural (52 percent) and mining (39 percent) sources. On the other hand, approximately 38 percent of the waste water is derived from residential, commercial, and institutional sources. The source of the remaining 62 percent of the waste water is industrial: 33 percent for primary metals; 28 percent chemical; 14 percent paper and allied products; 10 percent petroleum and coal; 5 percent food products; and 10 percent for textiles, rubber plastics, machinery, transportation equipment and all other manufacturing. From these statistics it appears that about 10 percent of all solid waste and practically all of the liquid waste generated originates in the more urbanized and industrialized regions of the country where nearly two-thirds of the nation's total population is currently living and working. These urban areas constitute only about eight percent of the total land in the United States.

Municipal solid waste differs considerably in composition from region to region and seasonally within any given region. However, the breakdown as presented in Table 27 is fairly typical. In this listing, it appears significant that approximately 80 percent of all municipal solid waste materials are of a combustible nature and that most of the remainder is made up of metal or glass waste products. This suggests that nearly all of the solid refuse now discarded could be reclaimed for energy production or resource recovery. Municipal liquid waste streams also vary greatly in chemical composition. The primary controlling factors for this in any given region for any particular season are the nature of the community (residential, commercial or industrial) and the percent of total sewage flow that is derived from industrial concerns, hospitals, institutional laboratories, and storm runoff from yards, streets and parking lots.

Industrial refuse generally can be divided into two categories, non-process and process wastes. Non-process wastes are those common to most industries, such as refuse derived from packaging, shipping, office and cafeteria activities. These types of materials usually are disposed of by the same methods and in the same facilities as those used for municipal waste disposal. Industrial process wastes are far more

Table 27. MATERIAL FLOW ESTIMATES OF RESIDENTIAL AND COMMERCIAL POST-CONSUMER NET SOLID WASTE DISPOSED OF, BY MATERIAL AND PRODUCT CATEGORIES, 1971[a] [c]

Product Category

In millions of tons (and %), as generated[b]

(Partial figures may not add up to totals because of rounding)

Material	Newspapers, books, magazines	Containers, packaging	Major household appliances	Furniture, furnishings	Clothing, footwear	Food products	Other products
Paper	20.3 (21.3)	22.2 (23.3)	—	tr.	tr.	—	8.7 (9.6)
Glass	—	11.6 (12.2)	—	tr.	—	—	1.0 (1.1)
Metals	—	5.9 (6.5)	1.7 (1.9)	0.09 (0.1)	tr.	—	3.6 (4.0)
Ferrous	—	5.1 (5.6)	1.5 (1.7)	tr.	—	—	3.4 (3.7)
Aluminum	—	0.7 (0.8)	0.09 (0.1)	tr.	—	—	0.09 (0.1)
Other non-ferrous	—	0.09 (0.1)	0.09 (0.1)	tr.	—	—	0.18 (0.2)
Plastics	tr.	2.8 (3.1)	0.09 (0.1)	0.09 (0.1)	0.18 (0.2)	—	1.5 (1.6)
Rubber and leather	—	tr.		tr.	0.45 (0.5)	—	2.7 (3.0)
Textiles	tr.	tr.	—	0.5 (0.6)	0.5 (0.6)	—	0.6 (0.7)
Wood	—	1.7 (1.9)	—	2.3 (2.5)	tr.	—	0.45 (0.5)
Total non-food product waste	20.3 (21.3)	42.6 (46.9)	1.9 (2.2)	3.1 (3.4)	1.2 (1.3)		18.6 (20.5)
Food Waste	—	—	—	—	—	20.3 (22.4)	—
Total Product Waste	20.3 (21.3)	42.6 (46.9)	1.9 (2.2)	3.1 (3.4)	1.2 (1.3)	20.3 (22.4)	18.6 (20.5)

a) Net solid waste disposal defined as net residual material after accounting for recycled materials diverted from waste stream.

b) "As generated" weight basis refers to an assumed normal moisture content of material in its final use prior to discard, for example: paper at an "air-dry" 7 percent moisture; glass and metals at zero percent.

c) "As-disposed" basis assumes moisture transfer among materials in collection and storage, but no net addition or loss of moisture for the aggregate of materials.

Table 27 (cont.) MATERIAL FLOW ESTIMATES OF RESIDENTIAL AND COMMERCIAL POST-CONSUMER NET SOLID WASTE DISPOSED OF, BY MATERIAL AND PRODUCT CATEGORIES, 1971[a] [12]

Product Category
In millions of tonnes (tons), as generated[b]
(Partial figures may not add up to totals because of rounding)

Material	Totals					
	As-generated weight[c]			As-disposed weight[d]		
	Million Tonnes	(Tons)	Percent	Million Tonnes	(Tons)	Percent
Paper	40.1	(44.2)	32.8	48.5	(53.4)	39.6
Glass	12.0	(13.2)	9.8	12.2	(13.4)	10.3
Metals	11.3	(12.5)	9.2	11.5	(12.7)	9.4
Ferrous	10.0	(11.0)	8.2			
Aluminum	0.9	(1.0)	0.7			
Other nonferrous	0.36	(0.4)	0.3			
Plastics	4.5	(5.0)	3.7	5.1	(5.6)	4.2
Rubber and leather	3.3	(3.6)	2.7	3.4	(3.7)	2.7
Textiles	1.7	(1.9)	1.4	1.9	(2.1)	1.6
Wood	4.4	(4.9)	3.6	4.4	(4.9)	3.6
Total nonfood product waste	77.5	(85.4)	63.3	87.1	(96.0)	71.1
Food waste	20.3	(22.4)	16.6	16.1	(17.8)	13.2
Total product waste	97.8	(107.8)	80.1	103.3	(114.0)	84.4
Yard Waste	22.7	(25.0)	18.5	17.2	(19.0)	14.1
Misc. inorganics	1.7	(1.9)	1.4	1.8	(2.0)	1.5
Total	122.4	(134.8)	100.0	122.4	(134.8)	100.0

complex in their composition and form, and many of these require special disposal methods and techniques to prevent possible serious adverse effects to some part of the environment. For example, it is estimated that about 9 million tonnes (10 million tons) of the 100 million tonnes (110 million tons) of industrial waste generated annually are presently or potentially hazardous to human health or living organisms. These wastes may be in the form of solids, sludges, liquids or gases and may consist of varying mixtures of toxic chemicals, as well as flammable, radioactive, explosive and biological-virological materials. A breakdown of the total volumes of these wastes produced by region within the United States is given in Table 28. Representative hazardous substances within the various categories of industrial waste streams are illustrated in Table 29.

SURFACE IMPOUNDMENTS

Practically every municipality, industry, and mining operation in the region uses unlined pits, ponds, lagoons or basins as part of the overall waste water treatment facility. Some of these merely serve as settling basins for suspended solid matter contained in the waste liquid. In others, organic materials in the waste stream are decomposed by aerobic or anaerobic bacterial action during a prolonged retention period. in still others, the impoundments are used primarily as evaporation-seepage basins for waste volume reduction.

The liquid component not consumed by evaporation is either routed to some surface-water course or else percolates through the bottom and sides of the impoundment to underlying aquifers. The solid or semi-solid sludge part of the waste settles to the bottom for eventual removal and disposal in a landfill or by spreading on nearby lands. In some instances, where the accumulated solids contain product-rich materials, they are reclaimed.

Surface impoundments are generally constructed by building dikes or excavating a basin in unconsolidated deposits. Some impoundments are lined throughout or in part with clay, concrete, asphalt or plastic membranes. Abandoned quarries and mines are sometimes used to hold untreated wastes.

There is a considerable range in the size of surface impoundments. They can be a series of cooling ponds receiving hundreds of litres per second of hot waste water and covering hundreds of hectares. On the other hand, a small unlined pit may only be a few metres in diameter and

Table 28. ESTIMATED INDUSTRIAL HAZARDOUS WASTE GENERATION BY CENSUS REGION IN TONNES (Tons) PER YEAR FOR 1970.[a)]

	South Atlantic		East South Central		Total	
	tonnes	(tons)	tonnes	(tons)	tonnes	(tons)
Inorganic in Aqueous	208,500	(230,000)	81,700	(90,000)	290,200	(320,000)
Organics in Aqueous	545,000	(600,000)	350,000	(385,000)	895,000	(985,000)
Organics	68,000	(75,000	40,000	(44,000)	108,000	(119,000)
Sludges, Slurries, Solids	72,600	(80,000)	8,600	(9,500)	81,200	(89,500)
Total:	894,100	(985,000)	480,300	(528,000)	1,374,400	(1,513,000)

a) States in South Atlantic Region:
Delaware
Florida
Georgia
Maryland & D. C.
North Carolina
Virginia
West Virginia

b) States in East South Central Region:
Alabama
Kentucky
Mississippi
Tennessee

Table 29. REPRESENTATIVE HAZARDOUS SUBSTANCES WITHIN INDUSTRIAL WASTE STREAMS.[9]

Industry	Hazardous Substances										
	Arsenic	Cadmium	Chlorinated Hydrocarbons[a]	Chromium	Copper	Cyanides	Lead	Mercury	Misc. Organics[b]	Selenium	Zinc
Mining & Metallurgy	X	X		X	X	X	X	X		X	X
Paint & Dye		X		X	X	X	X	X	X	X	
Pesticide	X		X			X	X	X	X		X
Electrical & Electronic			X		X	X	X	X		X	
Printing & Duplicating	X			X	X		X		X	X	
Electroplating & Metal Finishing		X		X	X	X					X
Chemical Manufacturing			X	X	X			X	X		
Explosives	X				X		X	X	X		
Rubber & Plastics			X			X		X	X		X
Battery		X					X	X			X
Pharmaceutical	X							X	X		
Textile				X	X				X		
Petroleum & Coal	X		X				X				
Pulp & Paper								X	X		
Leather				X					X		

a) Including polychlorinated biphenyls.
b) Acrolein, chloropicrin, dimethyl sulfate, dinitrobenzene, dinitrophenol, nitroaniline, and pentachlorophenol.

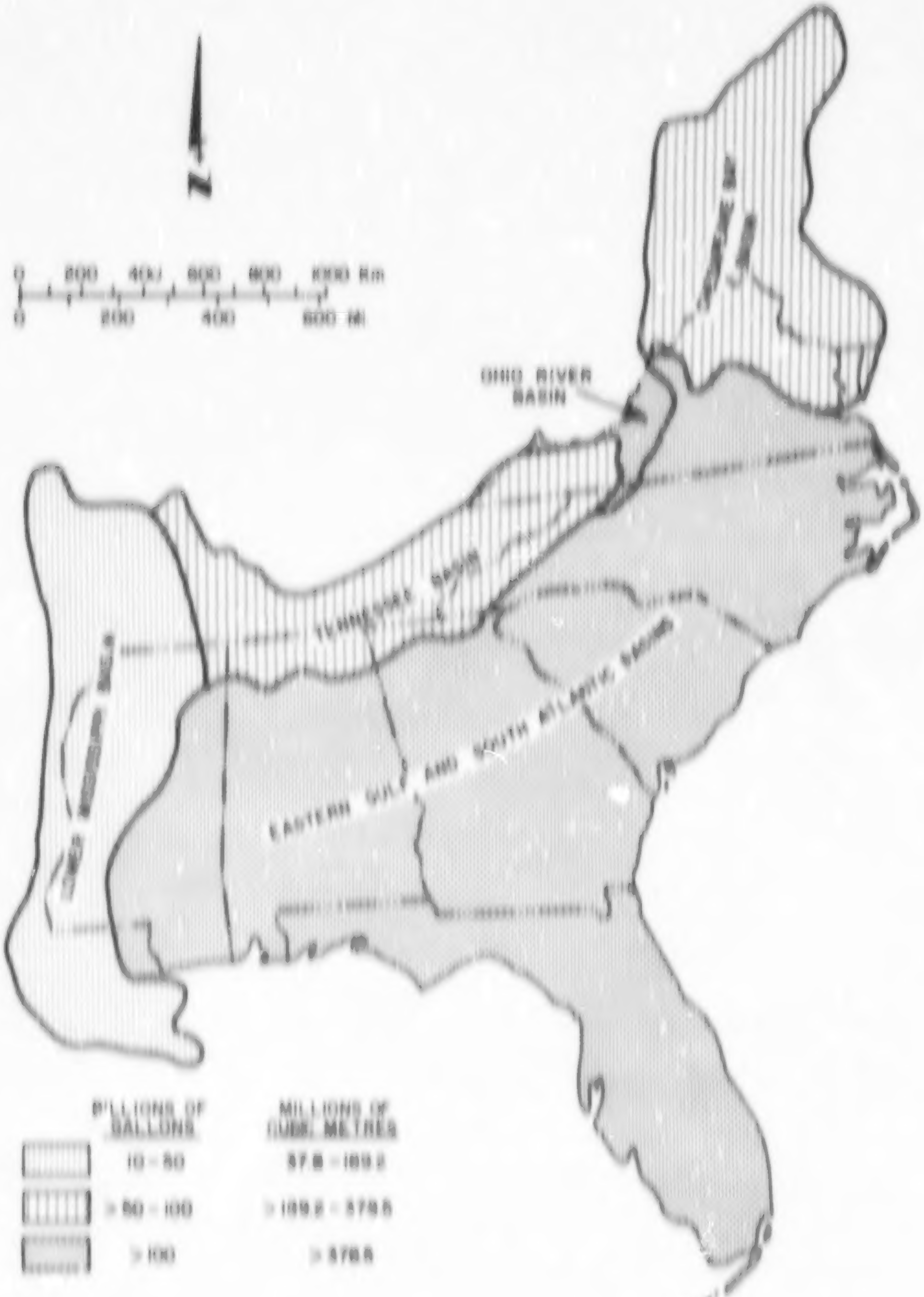
used to dispose of highly toxic wash water from a photographic laboratory. Most lagoons, pits, and basins are relatively shallow, usually less than 3 m (10 ft) in depth.

Complete statistics on the numbers and locations of surface impoundments have never been compiled for the Southeast. However, data from a few states serve to illustrate the use of surface impoundments in treatment facilities. In Mississippi, a 1972 regional inventory of impoundments for facilities with a volume greater than 61,700 cu m (50 acre-ft) was compiled from an aerial survey. A total of 87 surface impoundments with a total capacity of approximately three million cu m (2,500 acre-ft), including industrial and municipal facilities, were inventoried.12) Generally, most of the lagoons inventoried had an average depth of less than 1.8 m (6.1 ft). In the study area, some of the states maintain centralized records of municipal and industrial waste water treatment facilities. Due to the quantity of information and the method of data storage, much of this information was not readily retrievable.

In Alabama, municipal waste treatment systems in 1972 utilized 144 lagoons, with a total flow of 273,000 cu hm/d (72 mgd), for waste treatment.13) A 1975 inventory for Georgia listed 491 lagoons, with a total flow of 276,000 cu hm/d (72.9 mgd), used for municipalities, private developments and institutional waste-treatment facilities. Only limited information is available regarding industrial waste-treatment facilities. A 1972 inventory of industrial waste-treatment facilities for Georgia reported a total of 142 lagoons used in the treatment process that received a total flow of 855,000 cu hm/d (226 mgd).14) A Bureau of Census report compiled the total volume of industrial waste water treated in ponds and lagoons in the United States during 1968. Figure 32 is an indication of the volume of industrial waste waters handled in the study area.

Because lagoons, pits, and basins are such a common means for treating, handling, and storing liquids and sludges, it is likely that thousands of these impoundments are present in the study region. Their potential for leaking many thousands of cubic meters (millions of gallons) per year of potentially hazardous materials into the ground-water system is significant enough to be of considerable concern to water regulatory agencies.

This concern is justified on the basis of a number of factors inherent to the design and operation of surface impoundments. First, few were designed with any consideration given to protecting ground-water quality, and many



N
0 200 400 600 800 1000 Km
0 200 400 600 Mi
OHIO RIVER BASIN
TENNESSEE BASIN
LOWER MISSISSIPPI BASIN
EASTERN GULF AND SOUTH ATLANTIC BASINS
BILLIONS OF GALLONS
MILLIONS OF CUBIC METRES
10 - 50
37.8 - 189.2
> 50 - 100
> 189.2 - 378.5
> 100
> 378.5

Figure 32. Distribution of total industrial waste water treated in ponds and lagoons in the southeast study area and associated river basins, 1968.15)

operate on the principle that at least some fluid will be lost to the ground. Typical is the so-called evaporation pond which contains industrial or municipal waste and only operates successfully in the humid southeast region if enough leakage is taking place through the bottom and sides of the impoundment to create additional storage space for continued waste discharges. Many unlined surface impoundments are located in geological settings that are highly favorable for leakage.

Lagoon and retention basin failures were found to be a problem in areas of carbonate terrane. These areas are prone to subsidence and sinkhole development, and often ground-water contamination results. Problems found during this investigation were land-surface collapse under lagoons and downward seepage through a thin cover that remains after lagoon excavation. In many lagoons, the limestone bedrock is exposed in the bottom.

Data on case histories collected in this investigation show that typical surface impoundments are in areas where pollutants have easy access to aquifers. In some of the states, no general guidelines have been enforced until recently regarding siting or designing new surface impoundments from the standpoint of ground-water protection. Consequently, lagoons, pits and basins are located and constructed to meet other criteria, such as convenience and lowest possible cost.

Even in the case of some lined impoundments, the potential for leakage can be significant. Various types of clay are probably the most universally employed lining materials. However, they are not impermeable, so that enough concentrated pollutants can leak from a large lagoon to damage ground-water supplies under certain conditions. For example, a lagoon 8.1 ha (20 acres) in size and 3 m (10 ft) deep lined with a 0.6-m (2-ft) thick clay blanket with a typical permeability of 41 X 10^{-6} m/day (0.001 gpd/ft^2) can leak about 5,680 cu m (1.5 X 10^6 gal) of fluid per year into the ground-water system. If the fluid is an industrial waste and little change in water quality from contact with the natural soil occurs before the pollutant arrives at the water table, then a potentially serious contamination problem can occur. If 305 m (1,000 ft) is the distance from the lagoons to the nearest well tapping the water-table aquifer, and ground water is moving toward the well at a rate of 0.15 m (0.5 ft) per day, it would take more than five years before the plume of contaminated water would be detected. Meanwhile, 28,400 cu m (7.5 X 10^6 gal) of the waste water would have leaked into the aquifer.

Another major concern is the general lack of metering of waste discharges into holding ponds, lagoons and basins. If losses of fluids to the ground-water system are taking place, this condition generally continues unobserved for extended periods. In addition, the use of monitoring wells to determine whether leakage is occurring and is affecting ground-water quality in the vicinity of existing surface impoundments is rare.

The types of wastes put into industrial lagoons, pits and basins are virtually limitless. However, only a relatively few industries generate the great bulk of the total lagooned waste water. Four major industrial groups generated about 91 percent of the total volume of waste water put into ponds and lagoons in 1968: paper and allied products, 29 percent; petroleum and coal products, 22 percent; primary metals, 22 percent; and chemicals and allied products, 18 percent.(15)

While numerous chemical constituents are contained within the waste waters of these major industrial groups, general constituent groups or parameters that indicate potential contamination can be identified. Table 30 lists the parameters for the above-mentioned key industrial groups which have significant ground-water contamination potential.

Case Histories

The results of the inventory of documented and potential ground-water contamination problems involving surface impoundments are summarized in Table 31. The tabulation is not comprehensive, because very few investigations have been undertaken to define the problem. In addition, few regulatory agencies or industries even recognize that a problem may exist.

In Pensacola, Florida, concentrated acid wastes from a fertilizer plant were disposed of in unlined pits from about 1889 to 1957. The area is underlain by a sand and gravel aquifer, with an approximate hydraulic conductivity of 17.4 m/day (57 ft/day), to a depth of about three hundred metres (a thousand feet). In the area, the sand and gravel aquifer is extensively developed for industrial, municipal and domestic water supply. Ground-water development for public supply was formerly centered to the southeast of the plant site. Generally, the water table slopes to the east. The contaminant plume migrated to the east and south (Figure 33). General chemical characteristics of the waste were low pH and high dissolved solids, hardness, sulfate, fluoride, calcium, and magnesium. A municipal well located 1.8 km (1.1 mi) east of the disposal pits was abandoned in about

Table 30. INDUSTRIAL WASTE WATER PARAMETERS HAVING OR INDICATING SIGNIFICANT GROUND-WATER CONTAMINATION POTENTIAL.16)

PAPER AND ALLIED PRODUCTS

Pulp and Paper Industry

COD
TOC
pH
Ammonia
Phenols
Sulfite
Color
Heavy metals
Nutrients (nitrogen
  and phosphorus)
Total dissolved solids

PETROLEUM AND COAL PRODUCTS

Petroleum Refining Industry

Ammonia
Chromium
COD
pH
Phenol
Sulfide
Total dissolved solids
Chloride
Color
Copper
Cyanide
Iron
Lead
Mercaptans
Nitrogen
Odor
Total phosphorus
Sulfate
TOC
Turbidity
Zinc

PRIMARY METALS

Steel Industries

pH
Chloride
Sulfate
Ammonia
Cyanide
Phenol
Iron
Tin
Chromium
Zinc

CHEMICALS AND ALLIED PRODUCTS

Organic Chemicals Industry

COD
pH
Total dissolved solids
TOC
Total phosphorus
Heavy metals
PCB's
Phenol
Cyanide
Total nitrogen
Vynal chloride

Inorganic Chemicals, Alkalies and Chlorine Industry

Acidity/Alkalinity
Total dissolved solids
Chloride
Sulfate
COD
TOD
Chlorinated Benzenoids
  and polynuclear
  aromatics
Phenol
Fluoride
Total phosphorus
Cyanide
Mercury
Chromium
Lead
Titanium
Iron
Aluminum
Boron
Arsenic

Table 30 (cont.) INDUSTRIAL WASTE WATER PARAMETERS HAVING OR INDICATING SIGNIFICANT GROUND-WATER CONTAMINATION POTENTIAL.[16]

CHEMICALS AND ALLIED PRODUCTS (cont.)

Plastic Materials and Synthetics Industry

COD
pH
Phenols
Total dissolved solids
Sulfate
Phosphorus
Nitrate
Organic nitrogen
Chlorinated benzenoids and polynuclear aromatics
Ammonia
Cyanide
Zinc
Mercaptans

Nitrogen Fertilizer Industry

Ammonia
Chloride
Chromium
Total dissolved solids
Nitrate
Sulfate
Organic nitrogen compounds
Zinc
Calcium
COD
Iron, total
pH
Phosphate
Sodium

Phosphate Fertilizer Industry

Calcium
Dissolved solids
Fluoride
pH
Phosphorus
Acidity
Aluminum
Arsenic
Iron
Mercury
Nitrogen
Sulfate
Uranium

Table 31. SUMMARY OF CASE HISTORIES FROM SURFACE IMPOUNDMENTS IN THE SOUTHEAST.

Type of Industry or Activity	Number of Cases	Principal Contaminants[a)]
Chemical	6	Acidity Ammonium COD Dissolved solids Fluoride Hardness Nitrate Oil Sulfate Total nitrogen TOC Turbidity Zinc
Municipal and institutional sewage waste treatment	5	Nitrate Sewage
Petroleum brine[b)] disposal pits	4[c)]	Brine
Agricultural[b)]	2	Acidity BOD COD Manure Total dissolved solids Total solids Sulfate

a) List includes only those contaminants determined by analysis or observation, thus, others may exist that were not determined by analysis.
b) These cases are discussed in other sections of the report.
c) Not the total number pits, but rather the number of fields where problems have been documented.

Table 11 (cont.) SUMMARY OF CASE HISTORIES FROM SURFACE IMPOUNDMENTS IN THE SOUTHEAST.

Type of Industry or Activity	Number of Cases	Principal Contaminants a)
Food processing	2	Chloride Sodium Unidentified organics
Textile	1	Dye
Metal plating	1	Acidity Aluminum Iron Phosphate Sulfate Zinc
Commercial waste disposal	1	Carbon black Unidentified organics
Recycling oil	1	Acidity Lead Oil sludge
Paper	1	Acidity Alcohols Formaldehyde Phenols Sodium
Mechanical repair shops	1	Diesel fuel Nitrate Oil Phenols Sludges (unidentified) Wash water

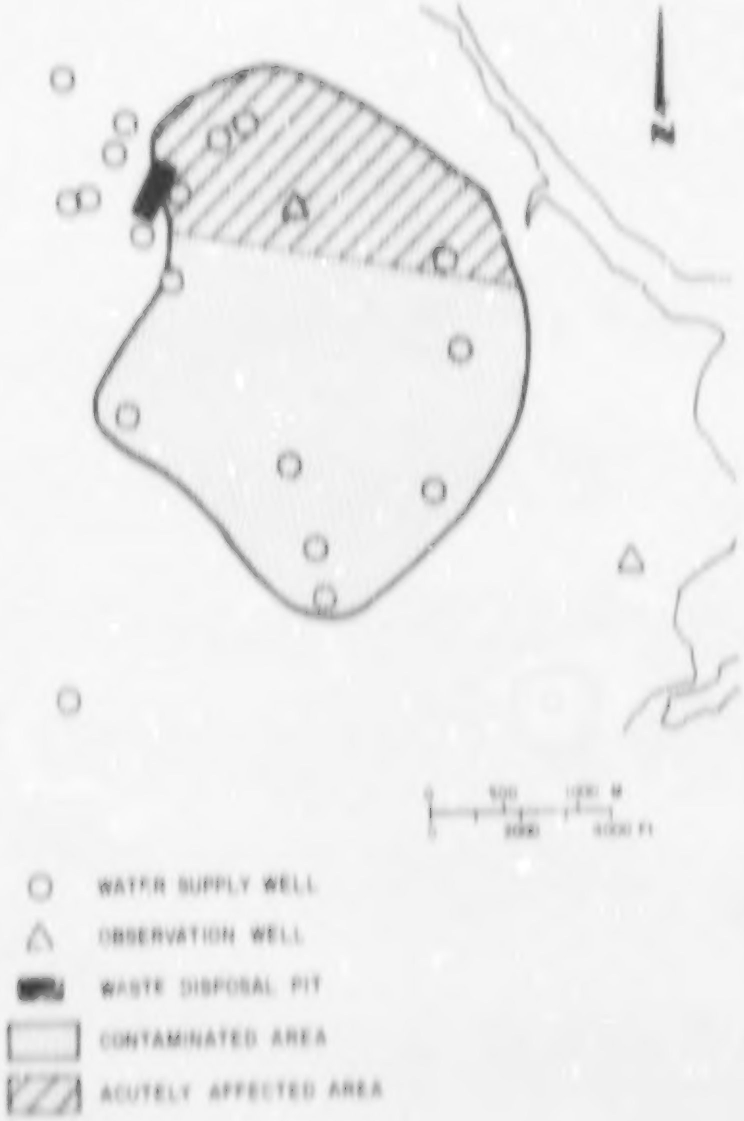

N
0 500 1000 M
0 2000 4000 Ft
○ WATER SUPPLY WELL
△ OBSERVATION WELL
■ WASTE DISPOSAL PIT
▭ CONTAMINATED AREA
▨ ACUTELY AFFECTED AREA

Figure 33. Extent of contaminant plume in 1972 in the Sand-and-Gravel aquifer, Pensacola, Florida.17)

1958. The industry has since abandoned use of the pits and now uses deep disposal wells. However, field determinations of water samples collected in 1975 indicate that the ground water is still contaminated.[17,18]

In northeastern North Carolina, waste water from a fertilizer plant was used to irrigate a small field on an irregular schedule from 1970 to 1972. In 1972 about three thousand cubic metres (eight hundred thousand gal) of a more concentrated waste nitrogen solution were disposed of in a temporary waste pond constructed with soil diking. Neither the sides nor the bottom of this pond were treated to prevent leakage of the stored effluent. The pond was filled with waste nitrogen solutions to a depth of about 1.7 m (5.6 ft) for about one year. During the irrigation period and after the waste pond was filled, water samples from a fresh-water pond located 60 m (197 ft) to the south had 400 to 500 mg/l nitrogen (ammonium plus nitrate-nitrogen). Prior to construction of the waste pond, the water-table gradient was toward the north and east; however, use of the waste pond and a drainage ditch locally reversed the gradient. The area is underlain by sandy sediments with discontinuous beds of clay. Generally, the contaminant moved downward and horizontally in the sediments. An underlying unit of silty clay at a depth of about 10 m (33 ft) and an upward hydraulic gradient from deeper confined aquifers prevent further downward movement of the contaminant.[19]

At the Savannah River Plant near Aiken, South Carolina, which is an ERDA facility for the processing of nuclear fuels, radioactive solid waste is buried and low-level radioactive liquid waste is disposed of through seepage basins on the site. The site is situated in the Coastal Plain and is underlain by generally unconsolidated sandy sediments. It is drained by five small streams that are tributary to the Savannah River. Liquid wastes are disposed in six seepage basins, and the depth to the water table ranges between 9 m (30 ft) and 18 m (60 ft) below land surface. All of the radionuclides disposed in the basins, except plutonium, have been detected in the surrounding ground water. Tritium is not sorbed in the soil, and therefore has migrated the farthest. Strontium 90 is poorly sorbed in the soils, and has migrated as far as 152 m (500 ft) from the basins. Soil sorption and/or radioactive decay have limited the movement of many other elements.[20]

Two lagoon failures due to sinkhole development have been reported in Alabama. Near Talladega, a sewage lagoon was excavated in alluvial sand and gravel deposits with bedrock exposed in several places. A short time after the lagoon was placed in operation, a sinkhole approximately 1.8 m (6 ft) in diameter and 0.6 to 1.2 m (2 to 4 ft) deep developed in the bottom of the lagoon draining the waste water. Near Centerville, a sewage lagoon was excavated in sand and gravel deposits. It was found that dolomite bedrock was near the lagoon bottom in two areas. One solutionally enlarged fracture was grouted with cement and the area covered with a plastic membrane. A compacted clay liner was placed over the bottom and sides of the lagoon. About two months after the lagoon was placed in operation, a sinkhole developed in the bottom draining the waste water.[21]

At Fort Gaines, Georgia, a sewage treatment lagoon designed to handle 306 l/sec (7 mgd) was constructed in a carbonate terrane. The lagoon was in use for two years when a sinkhole developed in the bottom draining the waste water. During operation, the lagoon never filled to its design level.[22]

Future Trends

Expanded effluent standards for industrial and municipal wastes that have been imposed almost everywhere in recent years are forcing an ever increasing treatment of many liquid waste streams before they are permitted to be discharged to streams. Such treatment usually involves additional suspended solids and bacteria removal, but may also include nutrient and other chemical reduction as well. Sludges also are being more carefully scrutinized and their disposal more rigidly controlled, primarily because of the possible harmful levels of hazardous chemicals or biological-virologic contaminants that they might contain. One result is an increasing use of surface impoundments in the waste treatment process. However, an increasing number of groundwater contamination occurrences from leaky waste ponds and lagoons is forcing the regulatory agencies to drastically restrict the use and operation of unlined basins throughout the region.

The development of guidelines, an approach being used by state agencies to protect ground water from contamination by landfills, might be considered for surface impoundments. However, before such guidelines could be established, additional research is required on the characteristics and effectiveness of the different materials available for artificial lining. Acceptable methods for metering loss of liquids from lagoons, pits, and basins have to be developed and tested. More information is needed on what happens to different types of soil beneath and around impoundments containing various wastes with respect to changes in permeability, adsorptive capacity, and potential for ion exchange. More should be learned about many of the wastes placed in surface impoundments, especially the municipal and industrial waste sludges, which if not already wet when impounded soon become wet from precipitation. Finally, identification of compounds that can be leached from these sludges along with their ultimate fate when they reach the saturated zone must be accomplished. In too many cases, not even the chemical make-up of the original material impounded is known in any detail.

What may be more important from an overall ground-water quality standpoint than the control of new surface impoundments are the thousands of existing and already leaking sites throughout the region. A major difficulty will be locating those that may be damaging ground-water quality. Many surface impoundments are on private lands and are therefore difficult to inventory, except by air. Industries and municipalities have not had to register the existence of surface impoundments with regulatory agencies in the past, and thus, no central statistical file exists in the various states on where and how they are used. Also, basins with a very small area can be as potentially dangerous as extensive lagoon systems, depending on such factors as the type of pollutant being lost, the rate at which leakage is taking place, the susceptibility of the aquifer to extensive contamination, and the proximity of wells supplying drinking water. These small basins would be difficult to locate even from the air.

A second difficulty is how to contain the pollutant and clean up the aquifer that has been contaminated. Regulatory agencies hesitate to place heavy economic burdens on the owner of the leaky surface impoundment.

Because of the problems inherent with attempting to remove a pollutant from an aquifer, cleanup operations when large volumes of contaminated ground water are involved are for the most part ineffective. In the long run, most of the pollutant is left in the ground. Cases of active ground-water contamination first reported decades ago are not uncommon. In some instances, ground-water contamination was discovered after an industry had gone out of business or abandoned the site. Cleanup in such cases can be difficult to enforce, and litigation over this and other conditions of ownership and responsibility can be time consuming and costly.

Most efforts toward containment or cleanup are hindered by what to do with the pollutant after it has been removed from the aquifer and brought to the surface. In many cases the contaminant is too toxic to discharge into a nearby surface-water body or the volume is too large to leave in the ground but too small to justify the construction of a special treatment plant on the site. If a nearby municipal or privately owned waste-treatment plant could be found to accept the effluent removed from the aquifer, then perhaps it could be taken away by tank truck at a reasonable cost. However, where the polluter no longer exists as a corporate entity, it is questionable as to who would pay for any corrective measures. Except for abandonment of the waste lagoon and affected wells, the problem remains unsolved.

LANDFILLS

Prior to about 1965, effective rules and regulations controlling the location and operation of municipal garbage dumps, landfills and industrial hazardous waste disposal grounds were nonexistent throughout the United States. Even today, large quantities of municipal, commercial and institutional garbage and hazardous waste produced by industry each year are disposed of on the land in an unsatisfactory manner. Formerly, landfill sites were typically abandoned sand and gravel pits, rock quarries, or gullies, hollows or sinkholes. Now, more and more attention is being given to selecting disposal grounds that are underlain by much less permeable materials, such as clays, shales, and similar fine-grained earth materials where adverse environmental effects can be minimized. Also, special dumping grounds for hazardous waste materials are being developed to replace those previously used, which were generally inadequate and unsafe from an environmental pollution standpoint. The hazardous waste component of domestic, municipal and industrial refuse is of special concern because of its potential for serious harm to public health.

Much of the hazardous industrial wastes still is deposited in municipal sanitary landfills or buried on private property that is presently not under regulatory control unless contamination from such sources is detected off the site or causes harm to others. For instance, most of the more than 250 million pesticide containers and unknown but suspectedly large quantities of unused or wasted pesticides in the United States each year are crudely buried, thrown away as trash into some gully, or else discarded in some nearby landfill with the daily domestic garbage accumulation. At least part of the estimated 154,300 tonnes (170,000 tons) of pathological wastes from hospitals each year in the United States also is buried and every household in the country yearly throws away one or more pounds of lead, cadmium, mercury, arsenic, or similar poisons from such common sources as paint, dry cell batteries, paper, cleanser products, and weed or insect killers. These become especially significant when it is considered that only a hundred grams (or 3.5 ounces) of many of these toxic metallic, organic, or chlorinated hydrocarbon compounds dissolved in a million kilograms (or pounds) of clean water may be harmful or even lethal to humans, animals, plants, and many aquatic life forms.

In the southeast region there are over 2,000 known active landfill sites that currently receive almost all of the residential, commercial and institutional waste material and a large portion of the total industrial waste produced each year. In addition, there are 48 known hazardous waste management facilities in the Southeast. Table 32 lists the number of land disposal sites in each state of the study area. Unfortunately, throughout the region there also are many abandoned land-disposal sites that in the past undoubtedly received large but unknown quantities of hazardous materials; the locations of most of these are unknown. These especially pose a particularly serious ground-water contamination threat. This is due to the fact that an evaluation of geologic and hydrologic conditions was rarely included among the various considerations that determined site selection for landfills.

Existing and abandoned landfills or dumps invariably were placed on land that had little or no value for other uses. The site chosen, for example, was in a marshland, an abandoned sand and gravel pit, an old strip mine, or a limestone sinkhole, each of which is a favorable environment for the development of ground-water contamination problems.

The processes that can lead to contamination of ground water from the disposal of wastes in landfills are relatively simple. The various organic compounds in refuse (with the exception of most plastics) are decomposed or stabilized by aerobic and anaerobic organisms to simple substances that will decompose no further. These products of decomposition include gases and soluble organic and inorganic compounds. If sufficient water is available from precipitation, surface drainage or from ground water in contact with the refuse, these compounds can be dissolved and ultimately recharge the ground-water reservoir or discharge into adjacent surface-water bodies.

Solid inorganic refuse, such as tin cans and metal pipes, can also be slowly dissolved by percolating waters, resulting in a solution with an increased concentration of metallic

Table 21. LAND DISPOSAL SITES IN THE SOUTHEAST.[23]

	No. of Known Land Disposal Sites	No. of Authorized Landfills	Special State Regulations for Hazardous Wastes	No. of Disposal Facilities for Hazardous Wastes	No. of Sites with Impermeable Linings	No. of Sites with Leachate Treatment Facilities
ALABAMA	143	23	No	9+	0	1
FLORIDA	500	179	No	Unknown	0	6
GEORGIA	625	125	No	3	0	0
MISSISSIPPI	274	0	No	1	0	0
NORTH CAROLINA	162	Unknown	No	Unknown	0	0
SOUTH CAROLINA	276	171	Yes	35	0	0
TENNESSEE	188	173	No	0	1	1
TOTALS	2,168	600		48	1	8

ions. Finally, disposal of liquid industrial wastes, septic tank pumpings, and waste-water treatment sludges can contribute to an overall increase in dissolved solids in water passing through the landfill. Leachate is that highly contaminated water generated by a refuse disposal site.

Changes in the composition of leachate and in concentrations of substances take place as the various pollutants move through the subsurface environment. Significant indicators of pollution in leachate from landfills containing municipal refuse include BOD (biological oxygen demand), COD (chemical oxygen demand), iron, chloride, and nitrate. The interaction of CO_2 (carbon dioxide) with soil and rock materials may contribute to the hardness of ground water in the area and result in the release of iron and manganese held on soil particles. In addition, biological pollution can be associated with waters discharging from a municipal landfill. Heavy metals and other toxic compounds can be found in ground water containing leachates from municipal landfills where toxic wastes have been accepted, and from private landfills serving particular industries where special types of wastes are dumped.

The concentration of chemical and biological pollutants travelling through soil decreases with distance from the landfill. The effectiveness, however, of such processes as adsorption, ion exchange, dispersion, or dilution varies considerably with the type of pollutant involved, the characteristics of the soil underlying the landfill, and geologic and hydrologic conditions at the site. Thus, no broad generalizations can be made.

The volume of leachate developed is a function of the absorptive capacity and areal extent of a particular landfill and the amount of recharge water available for infiltration. Most landfills have a relatively flat surface with no vegetation, which is more conducive to infiltration than to runoff and evapotranspiration. They are normally covered with a relatively coarse-grained material, again increasing infiltration efficiency. Therefore, it is reasonable to assume that at least one-half of the annual precipitation can become recharge to the ground-water reservoir, after it has come in contact with the solid waste contained in the landfill. Average annual rainfall in the southeast region ranges from less than 889 mm (35 in.) to more than 1,524 mm (60 in.) per year. Thus a 40.47-ha (100-acre) site would be capable of producing from 179.8 million l (47.5 million gal) to 308.5 million l (81.5 million gal) of leachate per year after field capacity of the refuse has been reached.

Experiments have been conducted to test the feasibility of diminishing leachate production of sanitary landfills by using the roots of transpiring plants to dry the refuse and surrounding soil. At Auburn University, full-scale models of landfill cores were constructed and filled with typical municipal refuse. Various trees and grasses were used to vegetate the landfill models, while another landfill was denied vegetation and used as a control. Although the lower two-thirds of the landfills became anaerobic, the vegetation thrived and roots penetrated the cover soil and the upper layer of refuse. The volume of leachate varied considerably in the different landfill models, as measured in lysimeters. The leachate volume under areas vegetated by pine and thorny elaeagnus was seven times less than under the unvegetated area, although the leachate from the vegetated area was twice as concentrated as that from the unvegetated area.[24] The effectiveness of various other types of leachate control methods is summarized in Table 33, along with the degree of use of these methods and an estimate of the cost involved.

Research on how long after abandonment a landfill can be expected to generate leachate has been minimal. However, one investigation under a grant from the U. S. Public Health Service to the Pennsylvania Department of Health sheds some light on this. A study was made of a landfill in southeastern Pennsylvania, part of which had been closed in 1950 but was still producing leachate. This was sampled along with leachate from a new section of the same landfill site still in operation in 1970. The comparison of the chemical characteristics of the two leachate samples is shown in Table 34. It should be noted that there is a difference of a hundred-fold or more in BOD and COD between the leachate from the old abandoned section and the new section of the landfill. Differences in specific conductance, ammonia nitrogen, and sulfate are not as significant. Although concentrations of iron and hardness are considerably lower in the leachate from the older portion of the landfill, this site must still be considered a source of contamination, even 20 years after being abandoned.[26]

In addition to the adverse effects of leachates on adjacent surface-water and ground-water bodies, the gas-forming characterisitcs of water mixed with refuse cannot be ignored. As water is added to the organic constituents in landfills, decomposition of these materials starts to take place. As this occurs, various gases such as methane, carbon dioxide and hydrogen sulfide are produced. Methane (CH_4) is a colorless, odorless gas that is highly explosive in concentrations of 5 to 15 percent when in the presence of oxygen. In a number of instances, methane gas has migrated from

Table 11. LEACHATE CONTROL METHODS[25]

	Effectiveness	Degree of use	Cost (examples)
NATURAL ATTENUATION			
Clay	promising research	unknown	natural
Silt	unknown	unknown	natural
Sand	unknown	unknown	natural
PREVENTING LEACHATE GENERATION	ranges from complete to partial control	limited	N.A.
COLLECTION AND TREATMENT			
Liners	promising research	limited	$1.50 to $4.00 per sq yd
Biological treatment	promising research	very limited	N.A.
Physical-Chemical	promising research	very limited	N.A.
Recirculation	promising research	very limited	N.A.
Spray irrigation	promising research	very limited	N.A.
IMMOBILIZATION			
Chemical stabilization	research progressing looks promising	limited but growing	$10 to $20/ton
Encapsulation	research progressing looks promising	very limited	$16/ton
Fixation and encapsulation	research progressing looks promising	not in use	$40/ton
VOLUME REDUCTION			
Dewatering	effective	widely practiced in water pollution	$5 to $20/ton
Incineration	effective for organics	moderate	$20 to $100/ton
DETOXIFICATION	varies widely by process and waste	limited to specific wastes	varies widely

Table 34. COMPARISON OF THE CHEMICAL CHARACTERISTICS OF LEACHATE FROM AN OPERATING SECTION AND A TWENTY-YEAR OLD ABANDONED SECTION OF A LANDFILL IN SOUTHEASTERN PENNSYLVANIA.[26]
(All constituents in mg/l, where applicable.)

	Operating Landfill	Abandoned Landfill
Specific Conductance (micromhos)	3,000	2,500
BOD	1,800	18
COD	3,850	246
Ammonia (NH_3 as N)	160	100
Hardness (as $CaCO_3$)	900	290
Iron (Total Fe)	40.4	2.2
Sulfate (SO_4)	225	100

NOTE: Sample collection in 1970.

landfills and accumulated in explosive concentrations in nearby sewer lines and buildings. Gas from some landfills has been known to kill nearby vegetation, presumably by excluding oxygen from the root zone. Carbon dioxide (CO_2) also is a colorless, odorless gas, but it does not support combustion. It is approximately 1.5 times as heavy as air and is soluble in water. The CO_2 may react to form carbonic acid (H_2CO_3), which can dissolve mineral matter such as carbonates in refuse and surrounding earth materials. As this occurs, the hardness and total mineral content of contiguous waters increase, as has been commonly detected in shallow wells located near landfills and dumps. The other primary objectionable gas, hydrogen sulfide, is generally considered objectionable because of its "rotten egg" smell. However, in relatively low concentrations form this particular gas is lethal.

Case Histories

In northeastern Virginia, a 30.4-ha (75-acre) sanitary landfill containing up to 30 m (100 ft) of solid waste is generating leachate which is moving along the contact of the solid waste and the original land surface. Additionally, the leachate has moved into, and saturated, the permeable saprolite (silt and sand derived as a weathering product of igneous and metamorphic rocks) and joints and fractures of the Wissahickon Schist. The leachate will ultimately discharge to nearby streams. Based on criteria in regulations, the landfill is properly designed and operated, and is located in a relatively favorable site. Renovation of leachate is taking place as it moves through 13 m (43 ft) of saprolite to the water table; except that the material is too permeable and the partially renovated leachate is contaminating the ground water. In order to control the leachate, the following have been recommended: 1) monitor wells located along the fracture traces in the schist; 2) recovery of part of the leachate from the ground by means of wells; and 3) spraying of recovered leachate over the landfill for further renovation.[27]

Shallow ground water around a county landfill in northeast Mississippi is being contaminated by leachate. Most of the leachate and contaminated ground water is moving toward streams. Low permeability materials underlying the landfill inhibit downward movement of the leachate. Contamination at the site is attributed to poor engineering and operational methods. The material used for cover is sandy and relatively thin and is not applied on a daily basis. The landfill is subject to excessive infiltration, erosion and siltation. Vegetative cover necessary for surface stabilization and transpiration of water is not maintained. Runoff is directed toward the fill because the final grade of the landfill is lower than that of the surrounding topography.[27]

A 30.4-ha (75-acre) abandoned shell pit west of West Palm Beach, Florida, has been used for disposal of solid waste since the late 1940's. When the dump was full in 1973, an estimated 1.9 million cu m (2.5 million cu yd) of refuse had been disposed. The waste material is in direct contact with the water table. Movement of leachate-contaminated ground water is through the shallow aquifer southeast toward West Palm Beach. Leachate has been detected in the immediate vicinity of the dump at shallow depth. However, a quarter mile south and east the water was not noticeably impaired by the leachate. Although contamination of ground water is occurring, it will not be detected until pumping to the southeast increases.[28]

In Haywood County, North Carolina, solid wastes from a paper mill were disposed of in a draw. Fluids generated by rain percolating through the waste penetrated the soil and contaminated the water-table aquifer. A water-supply well was contaminated by chlorides and phenols and had to be abandoned. Other characteristics of the contamination were a lowering of pH, high iron and manganese concentrations, and increased hardness and COD. Ten monitor wells have been installed to determine the extent of contamination and the direction of movement.[29]

Disposal of latex waste has resulted in ground-water contamination in Walker County, Georgia. Although two latex operations were disposing of their wastes in the same general area, it was not possible to determine which was responsible. One latex producer dewaters his waste prior to disposal (an operation now required by the State of Georgia) and the other disposed of his fluid latex wastes in shallow pits at the site. Quantities of latex disposed at the landfill range from 344 to 612 cu m (450 to 800 cu yd) of dewatered wastes per month for one company to 45,420 l (12,000 gal) per month for the other company. After disposal of the liquid wastes in the pits located 168 m (550 ft) uphill from a small spring-fed stock-watering pond, milky latex wastes contaminated the pond. Another disposal site is located around a large sink. Water flowing through the solid latex wastes flows down the sink and exits from nearby springs where the milky color was observed.[30,31]

Shallow ground water in the vicinity of the Broward County Central Disposal Landfill, Florida, is contaminated by leachate at depths of 0-6 m (0-20 ft). Contamination at 27 m

(90 ft) was not observed, because ground-water movement is primarily lateral and not vertical. Some distance downgradient the leachate generated by the solid waste portion of the landfill was rejuvenated. However, the organic leachate generated from septic tank sludge disposal sites did not change character due to filtration and renovation processes in the soil. Ground water moving from the northwest passes through the site toward the southeast under a hydraulic gradient of 0.5 m/km (2.5 ft/mi) during the dry months and slightly more than 0.2 m/km (1 ft/mi) during the wet months; the gradients are locally affected by pumping in nearby rock pits and wells, drainage canals, and the pattern of the rainfall. An increase in the generation of leachate and the extent of the contamination of the Pamlico Sand, the upper part of the Biscayne aquifer in this area, was noted after the landfill site was covered with a slurry of material ranging from silt to coarse gravel. It is not known how far the leachate has moved toward the southeast, past the last monitor well.32)

In Georgia, state environmental protection officials have noted some interesting geographical occurrences of leachate from landfills. In the northern part of the state, where generally low to moderate permeability crystalline rocks are present, leachate emanates as seeps along the slopes or at the toes of the landfills. At some of the sites, waste material was emplaced over existing springs or streams. In the southern part of the state the earth materials are much more permeable and leachate is rarely seen. The greatest risk to ground-water quality occurs at the site of landfills immediately below the Fall Line where Cretaceous and Eocene aquifers are recharged, and in the southwest where the Eocene limestone aquifer is recharged. In general, it is the agency's opinion that only the water-table aquifer will become contaminated. Monitoring programs have been started at some sites, with several in the vulnerable recharge areas of the above-mentioned important aquifers. Additionally, at four metropolitan Atlanta sites, underlain by the relatively impermeable crystalline rocks, leachate collection systems are being installed because of surface-water contamination.33)

In southwestern Georgia in the recharge area of the Eocene limestone aquifer, a landfill poses a considerable threat to ground-water quality. The landfill is situated on the flood plain of a river and is contributing contaminants to the surface water. Additionally, the alluvial deposits are quite thin and permeable and are underlain by active and potential sink structures. Attempts to relocate the landfill are compounded by the possibility of direct recharge to the Eocene (Ocala) limestone aquifer if ground at higher elevations is utilized. Monitor wells have been recommended for the present landfill site on the flood plain.[33]

Considerable leachate is being generated by a county landfill in northwestern Georgia, with the leachate being observed in a small stream adjacent to the site. The site is underlain by a cherty residuum of the limestone that occurs in the area and some of the leachate is probably contaminating the locally fractured and cavernous limestone.[33]

A large municipal landfill in northern Alabama was sited in an area subject to high water table and collapsing sinkhole structures. An older portion of the landfill lies in a flood-prone area. No hydrogeologic criteria were used in selecting the site. Leachate movement is toward the south and probably downward into the cavernous limestone. At least the lower portion of the refuse in the landfill is saturated at some time during the year. The likelihood that ground-water contamination is occurring at the landfill is reinforced by an incident nearby in which sewage from a digester at a local sewage treatment plant south of the landfill entered a collapsed sinkhole under the digester and exited from a spring located 1.8 km (1.1 mi) southeast.[34]

Leachate from the 58th Street Solid Waste Landfill in Dade County, Florida is reportedly moving toward municipal well fields located 3,350 to 3,960 m (11,000 to 13.000 ft) east of the landfill. The leachate may have migrated more than half the distance between the well fields and the landfill. From data supplied, it is estimated that the leachate plume is over 18 m thick, 600-1,200 m wide, and 1,200-1,525 m long (60 ft thick, 2,000-4,000 ft wide, and 4,000-5,000 ft long). The direction and rate of movement of the leachate in the Biscayne aquifer are affected by heavy pumping from the municipal well fields.[35]

The construction of new residential areas on abandoned landfills, as cities and suburbs expand, has been a common occurrence in the region. In Richmond, Virginia, it has been reported that between 400 to 500 privately-operated dumps were active during the Civil War period. After the Second World War, with the explosion of residential construction, more recently active landfill areas were utilized for new residential developments. Numerous homes, schools, and other buildings were constructed on landfilled areas creating problems directly related to such activities. On January 8, 1975, a woman suffered first-degree burns when an explosion occurred in her living room, presumably from methane gas; the apartment door and two windows were blown out. Since then 1,000 families living on or near landfill sites have had to keep their windows open for fear of explosion or suffocation by methane gas, which is generated by the decomposing materials in the landfills. Two elementary schools have also been closed due to the buildup of hazardous levels of methane gas. Movement of the gas from the landfill takes place along the path of sewer lines or permeable zones within the rock surrounding the landfills.[36]

Future Trends

Because water pollution associated with landfills is becomming a real problem, state and other regulatory agencies in the region are in the process of preparing new regulations or modifying old ones to better control this activity. To a large degree, these are directed toward the design and siting of new municipal landfills. Industrial landfills will continue to be difficult to control, if located on a particular plant property unless more successful methods for inventorying solid-waste sites are developed, perhaps using advanced aerial photographic techniques.

New regulations normally call for geologic and hydrologic investigations of proposed sites and require such information as water-table elevation; direction of ground-water flow; distances to existing well supplies in the area; depth, thickness, and character of the overburden; and details of the bedrock aquifer. Although there is much variation in the details included in regulations and guidelines, a 152-cm (60-in) separation between the highest anticipated level of the water table and the base of the landfill is a typical requirement. A buffer zone of 15 to 30 m (50 to 100 ft) between the refuse area and the property boundary is called for by most agencies. Distances to the nearest operating wells normally are not specified but are to be determined on a case-by-case basis. Finally, the majority of new regulations call for 1) the sloping of the surface of the landfill to maximize runoff and minimize infiltration, 2) prohibition or curtailment of the dumping of hazardous or toxic solid and liquid materials, and 3) installation of monitoring wells.

Undoubtedly, these new regulations and the greater interest on the part of public agencies will help to reduce some serious ground-water contamination problems that otherwise would have occurred. However, the guidelines are based on insufficient research into such factors as the true character of leachate from various types of landfills, the ability of different soils to reduce the concentrations of different types of leachates, and the effects of landfill cover material, slopes, and thickness on infiltration of precipitation. Therefore, it is not known how effective the new codes will be in actually preventing ground-water contamination.

Some new landfills in the region are being constructed with clay or synthetic liners. These are used in combination with a system of drains to collect leachate before it can seep into an underlying aquifer. The major problems involved with this approach are the lack of experience and difficulties in the collection and treatment of leachate. Undoubtedly, the use of liners will be required more and more in the study area, especially where critical aquifers would otherwise be threatened or where nearby existing landfills have already been proven to be sources of ground-water contamination.

Another approach being considered in landfilling is to reduce the volume of solid waste to be handled. Alternatives already in practice or proposed include incineration, pyrolysis, composting, or recycling. All of these either create other environmental hazards, such as air pollution in the case of incineration, or are not economically attractive enough. Thus, solid-waste generation will probably continue to increase at an accelerating rate, unless environmental restraints on siting, including requirements for artificial liners, make the various alternatives listed above economically more attractive. Finally, concern over air pollution and surface-water quality may actually lead to a greater use of the land for disposal of wastes that formerly were discharged into these other two environments.

With the trend toward greater use of wells by public agencies as a means of monitoring ground-water quality, it is reasonable to predict that there will be an acceleration in the discovery of new problems at existing landfills. Unfortunately, adequate alternatives for eliminating the landfill as a source of contamination have not been developed, and, because of this, there do not appear to be any clear-cut guidelines or policies that can be followed. The same holds true for containing or removing the pollutant after it has entered the ground.

Contouring or grading and then covering the landfill with relatively impermeable material on which soil can be placed and vegetation established is being attempted at a number of sites in the region as a means of limiting the formation of new leachate. However, not enough history on this method has been developed to comment on its potential for success. Pumping from properly spaced wells is another alternative for containing or removing the pollutant, but this has been proposed only as a last resort. Pumping is a slow and costly process, which is not always successful and can create other serious environmental problems. Research on these aspects of ground-water quality protection is presently lacking, particularly in the areas of methodology and technology development for effective and economical leachate reduction, collection and treatment. Even now the operators are being forced to line and cover landfill sites, often with materials that have only a relatively short service-life expectancy. Also, they generally are required to collect and treat all leachates before discharge to any part of the environment. Both of these requirements, in effect, ignore two different yet closely interrelated realities of the situation. The first is that after landfill leachate collection is started, it must continue until decomposition of the refuse ceases and no more leachate is produced. When it is considered that such stabilization may not take place for years after the site has been completely filled and abandoned, it follows that any leachate collection system must be considered as a long-term and potentially very expensive venture. Some attempts are now being made to expedite the refuse decomposition process by adding water and oxygen at controlled rates. Also, leachate recycling to the disposal grounds shows some promise of hastening the waste decomposition process. However, the end product of all of these processes is a more concentrated leachate than before, a fluid that might be even more difficult and costly to treat. The second often ignored factor is that no economical way of actually treating such fluids now exists.

UNDERGROUND STORAGE OF WASTE FLUIDS AND SURPLUS WATERS

Subsurface injection of all types of waste fluids and surplus waters through wells has been practiced for many years, but injection of industrial and municipal wastes has become common only recently. The injection process need not require closed systems under pressure; that is, gravity drainage wells are considered to be injection wells also. One reason for the increasing use of injection wells is the newly enacted Federal and state water-pollution control laws that discourage or prohibit the discharge of waste fluids to surface-water bodies. Initially, it was believed that injection wells could provide ultimate disposal, but over the years, it has become increasingly obvious that subsurface disposal is at best temporary storage. Therefore, the terms storage and disposal are used interchangeably in this section of the report. It should also be noted that injection is not a waste treatment method. There is little evidence to suggest that storage underground is conducive to degradation of contaminants, except in cases involving acid wastes injected into limestone and short-lived radionuclides.[25]

Two general categories of fluids are being handled by injection wells: low volume, high toxicity fluids which are biologically hazardous even in small quantities and therefore must be isolated from the bioshpere; and high volume, low toxicity fluids that might have future uses. The high toxicity fluids can be lethal in minute quantities and are of limited degradable potential. At the present time, treatment by other methods may be technically or economically unfeasible. Although low toxicity wastes may be detrimental to human health, their effect is usually not deadly. The huge volumes of low toxicity fluids are the major problem. That is, there is too much waste to be conveniently manipulated by the more commonly employed disposal or treatment methods.[25]

The primary concern over contaminating potable water is with the chemicals involved. Fluids injected into wells can range in composition from rain water, through treated sewage effluent, to highly toxic chemical and radioactive wastes. A partial list compiled during this study of injected wastes in the Southeast is shown in Table 35. Of 268 industrial and municipal waste injection systems inventoried in the United States, 48.9 percent of the wells were operated by chemical, petrochemical, and pharmaceutical manufacturing firms, where toxic and refractory wastes were common.[37] Little is known about the chemical reactions of injectants underground, both with the formation and the formation fluids. Many reactions may occur under conditions of subsurface heat and pressure that do not occur at room temperature and atmospheric pressure. In those cases where more than one type of fluid is injected, the resulting mixture may produce some completely different exotic compound.

The growing and varying use of injection wells implies an increasing competition for available underground space. Among the many problems associated with injection of wastes, in a heavily industrialized area where many disposal wells are used, are the possible chemical and/or biological interactions of the different fluids and the effects of pressure build-up when a number of wells are located in a relatively small area and completed within the same hydrogeologic unit. For example, at a waste injection site in Florida and at a brine injection site in Mississippi, the natural hydraulic gradient has already been reversed over a large area, which is directly related to the injection practices at the sites.[38,39]

Table 35. WASTE PRODUCTS INJECTED AT PERMITTED FACILITIES IN THE SOUTHEAST.

- acids (inorganic)
  - fluosilicic
  - hydrochloric
  - nitric
  - sulfuric
- acids (organic monobasic)
  - acetic
  - formic
- acids (organic diabasic)
  - unidentified
- adiponitriles
- agricultural chemical wastes
- ammonia
- ammonium salts
- bicarbonates
- BOD waste
- carbonates
- caustics (unidentified)
- chlorides
- chlorobenzilate
- COD waste
- cyanides
- cyanogen chloride
- diazone
- dimethylterephthalate by-products
- esters (unidentified)
- fluorides
- furfural (an aldehyde) by-products
- hexamethylene-alcohols
- hexamethylene diamine
- industrial chemical wastes
- inorganic compounds (unidentified)
- iron chloride
- iron sulfate
- ketones (unidentified)
- methanol
- municipal waste treatment plant effluent
- "oil and grease"
- organic compounds (unidentified)
- organic nitrogen
- pesticide manufacturing waste
- phenols
- phosphates
- sodium carbonate
- sodium chloride
- sodium sulfate
- sodium sulfite
- sulfates
- sulfides
- sulfites
- steel pickling liquor wastes
- sugar plant wastes
- surfactants
- synthetic rubber manufacturing wastes
- triazines
- waxes (unidentified)

Several routes of contamination followed by injected wastes have been recognized, including[63]:

- direct emplacement into potable water zones;
- escape into potable water zones by failure of well casings or grouting;
- upward migration from receiving zones along the outsides of casings;
- leakage through unsuitable confining beds;
- leakage through abandoned or active wells; and
- migration to potable water zone of same aquifer.

In investigations into problems arising from the failure of injection wells at various locations in the Southeast, a number of routes of contaminant migration were identified. Many shallow drainage wells contaminate potable ground water by direct placement into fresh-water zones of an aquifer. At two injection sites, one in Florida and another in North Carolina, injection well failure and unsuitable confining beds were the possible causes for leakage into overlying aquifers. At a site in Mississippi, waste injected through a well migrated to a nearby monitor well and backflowed as a result of pressure buildup from other waste injection in this area. These are discussed in greater detail in the following case histories.

Case Histories

As of 1974, a total of 19 disposal wells had been permitted in four states within the study area. These were distributed as follows; five in Alabama, nine in Florida, one in Mississippi, and four in North Carolina. Of these, only six were operational, one each in Alabama and Mississippi and four in Florida. Oil field brine injection, injection for secondary petroleum recovery, and private domestic sewage disposal wells were not included in the inventory.[37] No problems have been reported in Alabama, however, there have been problems in Florida and North Carolina.

At Belle Glade, Florida, during the period from December 1966 to June 1973, over 3 billion l (800 million gal) of industrial waste from a furfural (an aldehyde) plant and a sugar mill were injected into a well completed in the lower Floridan Aquifer. The temperature of the waste ranged from 71 to 103°C (160 to 217°F); the pH from 2.6 to 4.5; the suspended solids from 500 to 2,800 mg/l; and the COD from 6,000 to 26,000 mg/l. The injection system consists of one injection well, one shallow monitor well located 23 m (75 ft) from the injection well, and one deep monitor well located 305 m (1,000 ft) from the injection well (Figure 34).

Over the period 1967 to 1971, the rate and volume of injected wastes increased, but the injection pressures remained stable or even decreased slightly. The injection rates range from 25 to 50 l/s (400 to 800 gpm) under injection pressures of 2.8 to 3.5 kg/sq cm (40 to 50 psi). Injection is seasonal with the sugar cane harvest, occurring during the fall, winter, and spring.

Although no pressure effects were evident in the two monitor wells, geochemical effects were observed. Slight increases in calcium concentration and alkalinity, and a slight decrease in the sulfate-to-chloride ratio, suggested that the waste front arrived at the shallow monitor well about 27 months after waste injection began. Because the temperature of the injected fluid was several times that of the native water, the hydraulic conductivity of the receiving zone and the confining beds may have increased by a factor of 2.5, increasing the probability of upward migration of the waste. After the waste was detected in the upper Floridan Aquifer, the injection well was deepened and the casing extended. The effectiveness of this remedial measure has not yet been determined.[40,41,42]

In 1968, a chemical company in North Carolina began injecting waste from dimethylterephthalate production, used in production of synthetic fibers, into wells completed in a saline zone of the Coastal Plain sedimentary units at depths of 259 to 305 m (850 to 1,000 ft). The system was experimental and designed to inject about 1,135,500 l/d (300,000 gpd) of waste effluent. The waste was composed of water containing approximately 15,000 mg/l acetic acid, 5,000 mg/l formic acid, and 500 mg/l methanol, with a pH range of 3.5 to 4.0. Due to hydrologic conditions at the site and failure of some injection wells, leakage of a portion of the waste into overlying aquifers occurred. In 1972, almost 4.5 years after the system was placed in operation, the injection operation was discontinued upon completion of a conventional waste-treatment plant.[43]

A sewage treatment plant at Pompano Beach, Florida, has been disposing of its waste waters through deep wells. Between 1959 and 1965, about 11.4 billion l (3 billion gal) of secondary treated waste waters had been injected into two wells 305 to 427 m (1,000 to 1,400 ft) deep. In 1965, some

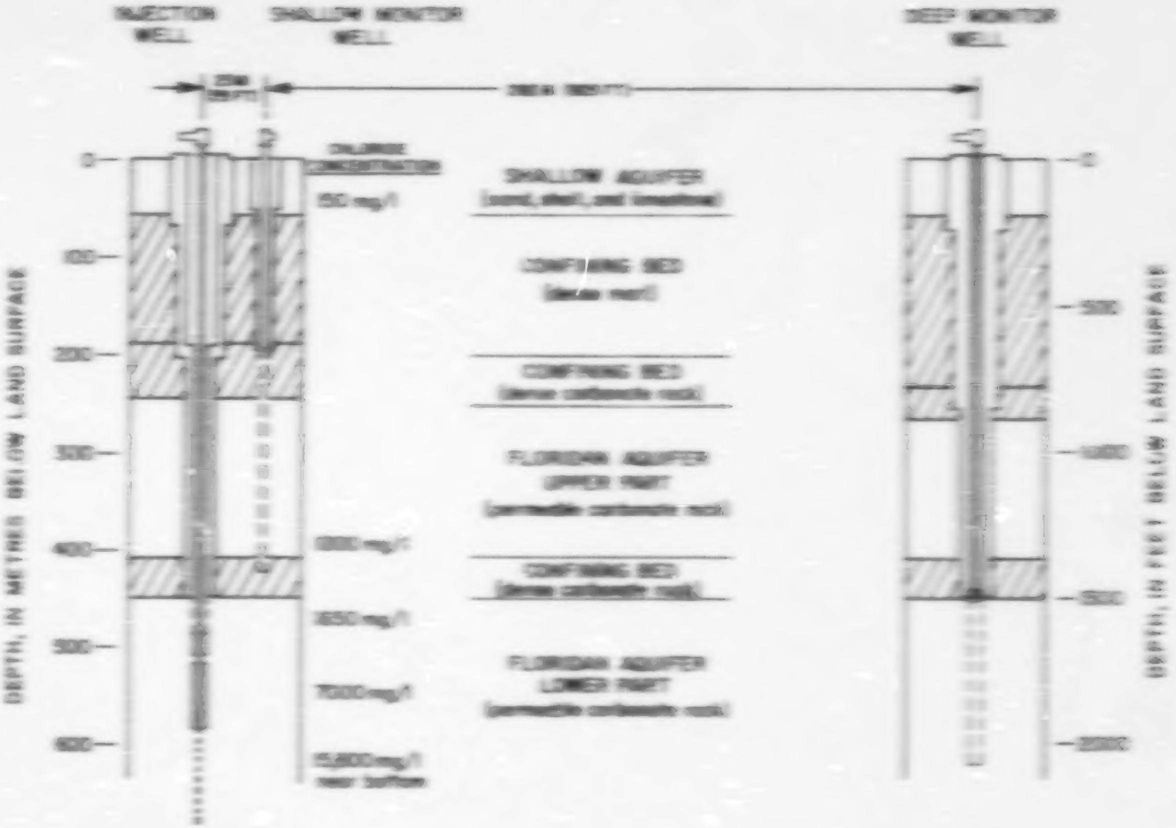

INJECTION WELL
SHALLOW MONITOR WELL
DEEP MONITOR WELL
CHLORIDE CONCENTRATION
150 mg/l
3650 mg/l
7000 mg/l
15,800 mg/l near bottom
SHALLOW AQUIFER (sand, shell, and limestone)
CONFINING BED (dense marl)
CONFINING BED (dense carbonate rock)
FLORIDAN AQUIFER UPPER PART (permeable carbonate rock)
CONFINING BED (dense carbonate rock)
FLORIDAN AQUIFER LOWER PART (permeable carbonate rock)
DEPTH, IN METRES BELOW LAND SURFACE
0
100
200
300
400
500
600
DEPTH, IN FEET BELOW LAND SURFACE
0
500
1000
1500
2000

Figure 34. Schematic diagram of well construction and hydrogeologic section, Belle Glade, Florida.[40,41,42]

wastes began to appear at land surface around the casing due to improper cementing. The casing was recemented and no evidence of contamination has appeared since.[44]

Thermal pollution of ground water as a result of injection of air-conditioning cooling water has been reported in Tallahassee, Florida, in the vicinity of the two state universities and the state government office buildings. The majority of the large air-conditioning systems in this area use ground water for condenser cooling. During the process, the water is heated and then returned to the aquifer through disposal wells. Both the cooling water supply wells and the disposal wells are completed in the same zone of the aquifer. As a result, the ground-water temperature in the area increased by 2 to 3°C (5 to 6°F).[45]

In the early 1960's, Florida State University experienced severe thermal pollution in its cooling water supply wells. Spent cooling water heated to 34.7°C (94.4°F) was disposed of through a well at a rate of 94.7 l/s (1,500 gpm). Three nearby supply wells completed in the same zone of the aquifer as the disposal well produced water with temperatures of 22.8, 30, and 32.2°C (75, 86, and 90°F). Wellbore current meter studies indicated that flow was restricted to a shallow section between 36.6 to 54.9 m (about 120 to 180 ft) in the wells. A tracer study indicated an apparent rate of ground-water movement of 24.4 m (80 ft) per hour. The disposal wells were redesigned to inject the heated water into a deeper zone isolated from the shallower supply zone by a 15 to 30 m (50 to 100 ft) thick zone of dolomite.[45]

Near Hattiesburg, Mississippi, two nuclear devices were detonated in 1964 and 1966 respectively, in the Tatum Salt Dome. The first device was exploded 826 m (2,710 ft) below land surface and the second one in the resultant cavity. Analysis of the post-shot data indicated that the radionuclides were contained within the cavity and in the fractures at the cavity margin.[39,46]

Although no water is known to be present in the salt dome, there are eight discrete artesian aquifers that overlie and are adjacent to the dome. All but one, the Cook Mountain Limestone, contain fresh water and are over 4.6 m (15 ft) thick. The original hydraulic gradient in each was toward the south-southwest. However, the gradient was reversed in the fresh-water aquifers by pumpage from water-supply wells and in the brine aquifer by oil well brine injection practices.[39,46]

From March to July, 1965, radioactive waste generated from drilling reentry operations was injected into an observation well completed in the Cook Mountain Limestone. About 1,279,000 l (338,000 gal) of water containing 38 Ci of beta and gamma activity and 3,253 Ci of tritium were injected. At the completion of the injection program, the well was sealed and a second monitor well was installed 91 m (300 ft) northeast in the same aquifer. Later, approximately 34,000 l (9,000 gal) of water containing 1.13 mCi of tritium flowed from this well. In March 1972, the well was capped to stop the flow.[46,47]

In September, 1972, water samples from the second monitor well were collected and analyzed and the presence of tritium was confirmed. A subsequent study and report stated that the contaminant migrated up the wellbore. In March, 1974, water containing 34,000 pCi/l flowed at land surface. This well was plugged to its total depth in August, 1975. No contaminants were reported in samples from other drill holes or in surface water at the site.[46]

Drainage wells have been used to dispose of urban storm runoff and to drain land for agricultural use. Numerous instances have been reported in which drainage wells were improperly used to dispose of municipal and industrial waste effluent. Ground-water contamination from drainage wells has been best documented in Florida, where there are an estimated 6,500 drainage wells.[48] The exact number of drainage wells is not known, because prior to 1939 such wells were constructed without permits.[49]

In Orange County, Florida, an estimated 400 drainage wells have been drilled since 1904, most of them in the Orlando-Winter Park area.[49] During the early 1930's about 18 drainage wells were used by the City of Orlando to dispose of sewage.[50] Many of the drainage wells are used to store storm water runoff. These wells receive runoff directly or from a storm drain system that discharges into a lake, where a drainage well is used to control lake levels.

Numerous cases of ground-water contamination by means of drainage wells, as a result of accidental spills or improper use of these wells, have been reported in Orange County. In one case, it is suspected that an accidental spill at a bulk fuel storage depot entered a storm drain system that discharged into a lake where water levels were controlled by drainage wells. Subsequently three domestic water supply wells in the area were contaminated with hydrocarbon and chlorinated hydrocarbon compounds. But the exact source of the contaminants could not be proven.[51]

At another location, a drainage well is used to dispose of surface drainage that contains water from dairy barn washings. Water entering the well had concentrations of sodium, potassium, chlorides, fluorides, and phosphates higher than natural water in the area. A well located 305 m (1,000 ft) down gradient was contaminated by the polluted water entering the drainage well.[49] At another location, a drainage well received water from tile drains underlying a citrus grove. Samples of the water entering the well in January 1964 contained 15 mg/l sodium, 15 mg/l potassium, 156 mg/l sulfate, 48 mg/l chloride, 2.0 mg/l fluoride, and 104 mg/l nitrate. All of these concentrations were higher than normal for the area, and the high concentrations of potassium and nitrate indicated pollution from fertilizer.[49]

Citrus processing waste, mainly pulp, has been disposed of in wells in the past. It has been reported that some water-supply wells in these areas are discharging methane gas. In 1943 the gas concentration from one well was approximately 74 percent methane, and by 1974 the methane decreased to only 24 percent.[50] One well in the Orlando area, operated by a citrus fruit processor, erupts every so often, spilling diluted orange juice and other citrus wastes onto company grounds. Decomposing citrus pulp, generating methane gas, probably provides the driving force for this orange juice geyser.[52]

The drainage capacities of the wells in the Orlando area have been estimated to range from 6.3 to 599 l/s (100 to 9,500 gpm). Although the total volume of recharge through drainage wells is unknown, it is undoubtedly high and is one of the reasons that no appreciable water-level cone of depression has developed in the Orlando-Winter Park area despite combined pumpage exceeding 189 million l/d (50 mgd) at times.[53]

Widespread contamination, primarily bacterial, has been reported in the upper part of the aquifer. In the lower zone, which is tapped by most public supply wells, only local, isolated problems have been reported. However, the potentiometric head of the lower zone is always below that in the upper zone in the area. It may only be a matter of time until increased downward movement of the contamination is evidenced.[53]

In 1964, during a six-week period, about 16,000 residents of Gainesville, Florida, were hit by stomach influenza, resulting in abdominal cramps and diarrhea. High concentrations of detergents had also been showing up in the city water supply during previous months. The source seems to have been a sewage treatment plant at the University of Florida which disposed of slightly more than 7.95 million l/d (2.1 mgd) into Lake Alice. Water from the lake flows into a drainage well, and from the point of the inflow to the drainage well, the contaminated water moved underground toward the municipal well field. The problem was resolved by chlorination and the subsequent closing of the sewage treatment plant.[54]

In Dade County, Florida, there are 1,500 permitted shallow drainage wells completed in the fresh-water Biscayne aquifer. These wells reportedly receive spent cooling water, swimming pool effluent, slaughter house waste, battery acid waste, metal plating waste, laundromat discharge, and similar matter.[54] Drainage wells have also been used in Hillsborough, Marion, and Leon Counties, Florida, to augment the natural drainage through sinkholes, in order to control storm water runoff.[45,55,56] In Georgia, drainage wells were installed to drain ponds for peat moss production. These wells were completed in fresh-water aquifers, resulting in a degradation of the natural water quality.[54] The North Carolina Highway Department has drilled 21 drainage wells to dispose of storm water runoff. The use of these wells is being phased out, but 15 still remain in use.[57]

It is not known how many disposal wells are in use in the study area, nor is it known what is being or has been disposed of in these wells. Some controls must be implementd which include all users, including the private homeowner.

Future Trends

Recharge of waste water through shallow wells probably will not be an important source of contamination in the Southeast as a whole. However, pollution problems may become severe, even threatening public-water supplies, in those areas of concentrated population and industry utilizing this means of disposal. More controls are needed to guard against use of shallow wells and drainage wells for disposal of waters that may contain chemical pollutants originating from industrial processes or from runoff from highways, urban areas, and agricultural areas that contain fertilizers, pesticides, and other organic and inorganic residues. Research is needed to determine the effects of these substances on ground-water quality in urban areas.

One serious problem associated with the deep underground disposal of hazardous waste liquids is the very high costs involved in site investigation to prove that the receiving aquifer is truly isolated by impermeable formations from all fresh-water zones. An exact definition of the controlling geohydrologic factors must be made prior to approval and construction of such an installation. Past practice in most cases of record was to define the suitability of some particular site to effectively receive and store a specific waste based on a review of available information, without test drilling.

Because subsurface injection is not a waste treatment practice but rather a waste storage practice, the chemical composition of the injecta is of particular concern. In many cases the injecta is highly toxic and contains non-biodegradable substances. Since there is no way to guarantee that an industry using an injection well at the present time will always exist and maintain the facility, a methodology must be established for the long-term maintenance and monitoring of the site and its vicinity. Thus, the long-term care requirements must be identified and adequately funded long before a site is abandoned. With regard to the land disposal of radioactive wastes, five states require disposal site operators to contribute to a fund for long-term care of the site. A study completed for one state suggested that the operator post a bond to cover these costs.[58] Other states could do much the same, that is, assess a fee based in part upon the design and type of waste storage site and in part on the volume of waste injected. This fund would accumulate until the site was abandoned by the industry. To protect citizens from the cost of long-term maintenance should a site be abandoned before sufficient funds are available, injectors could execute a performance bond, the amount of which would decrease as the long-term care fund grows.

LEAKS AND SPILLS

Pollutants from leaky and ruptured buried pipes, sewer lines, and storage tanks can directly enter and contaminate aquifers. Within the study region, the principal pollutants from these sources are sewage, storm water, and petroleum products. Chemicals used in industrial processes have also been reported as contaminants in a number of cases.

Exfiltration and infiltration commonly occur in sanitary and storm sewers. A system which was poorly designed and improperly installed or which contains old pipelines in disrepair, often leaks substantial quantities of poor-quality water into the soil system, eventually leading to contamination of an aquifer. Storm sewers are especially subject to exfiltration because joints normally are not completely sealed against leakage.

Petroleum and petroleum products are pumped through hundreds of miles of transmission pipelines and are contained in thousands of home fuel and gasoline station tanks throughout the region. Interstate and intrastate transportation pipelines are regulated, but they are still subject to accidental rupture and external corrosion.

If a leak of gasoline, oil, or a chemical fluid occurs in the soil zone above the water table, the liquid pollutant will either remain in the vicinity of the leak, move within the backfill in the trench or excavation, or migrate downward through the natural soil under the influence of gravity. The actual route and rate of travel taken by the pollutant depend on several factors including the volume of fluid released, the comparative permeabilities of the soil materials in the vicinity of the excavation, and the density, viscosity, and miscibility of the liquid. If the fluid entering the soil system is not completely adsorbed on soil particles, it eventually may reach the water table, and if miscible with water, move into the saturated zone. Subsequent rainfall can drive the pollutants coating the soil particles down to the saturated zone and add to the contamination of the water-table aquifer.

Methods used for the control and solution of problems caused by leakage from tanks and pipelines have been only partially successful, especially with regard to hydrocarbons. Repairs to the source of contamination are, of course, immediately undertaken, but in a number of cases, it was not possible to detect the source. Flushing the area with water has been reported as a method for attempting to dilute the pollutant in the shallow aquifer zone. Ruptured tanks have been dug out, and to prevent future problems, clay barriers have been installed in the excavation before a replacement tank was buried. Also, trenches and wells for skimming have been dug to remove hydrocarbons from the water table. Nevertheless, well owners in some areas of the region report that taste and odor problems from petroleum contamination of aquifers have existed for 20 to 25 years, in spite of all abatement efforts.

Each year accidental spills and improper management of hazardous and non-hazardous liquid materials at their points of use or storage result in an appreciable number of groundwater contamination occurrences thoughout the Southeast. In those cases where the volume of spilled fluids is large, direct infiltration to surficial aquifers usually takes place within a few weeks. In other cases, where intermittent applications merely result in saturation of the upper soil, ground-water quality deterioration in the vicinity of the spill area usually takes place during subsequent natural recharge periods, perhaps several months later. Activities leading to spills and surface discharges generally can be separated into three main categories: poor "housekeeping" and failures of above-ground tanks and pipelines; indiscriminate dumping of waste products; and accidents involving vehicular surface transportation of fluids.

Poor "housekeeping" practices on industrial plant grounds and around commercial establishments, airports, service stations and farms appear to be the major cause of those ground-water contamination instances inventoried. Most of these result from boil-overs and blow-offs, from overpumping during transfer of liquids to or from storage and carriers, from leaks in faulty pipes, tanks, and valves in production or distribution systems, and from poor control over waste discharges and storm-water runoff.

Contamination of ground water also has occurred in the southeast states from the indiscrimate dumping of pollutants on the land surface, especially waste hydrocarbon products at service stations and other types of small commercial establishments. When it is considered that several millions of gallons of such waste materials are discarded in the region each year, it seems amazing that many more actual cases of ground-water contamination from this source were not revealed during the present study. The probable reason why more were not reported is that such occurrences are so common and individually affect so small a part of any given aquifer that they are largely accepted as a not-too-unusual or an unimportant happening and are, therefore, not reported to any public health or environmental protection agency. This is not the case in accidental spills of hazardous materials resulting from train or truck wrecks, which, because of their potential harm, commonly receive wide publicity and immediate attention. However, the clean-up measures taken are not always those that will prevent ground-water contamination.

During the study an attempt was made to assess the potential impact of surface leaks and spills on ground-water quality. Data obtained from the Environmental Emergencies Branch of the Environmental Protection Agency Region IV office (Atlanta, Georgia) were used to determine what proportion of fluids spilled or leaked onto the land surface might reach the water table. The tabulated information came under two categories: oils and hazardous material. Under oils, the principal constituents were various hydrocarbon products with some minor amounts of oleoresins and vegetable oils. Those substances included in the hazardous materials consist of a wide variety of chemical compounds.

A summary of the data for six states is presented in Tables 36 and 37. It should be pointed out that the summary does not include every incident in each of the states, but only those reported with volumes recovered, lost to surface-water bodies and remaining on the ground. As can be seen in almost all cases in both tables, only a small percentage of the volume spilled or leaked was recovered. In addition, the methods of disposing of the recovered materials are, themselves, potential sources of ground-water contamination. Cleanup operations, in many areas, involve recovery of fluids from bodies of water by means of pumping, skimming, or absorption. The fluids and absorptive materials are either burned, recycled, buried on-site, or disposed of in landfills. In the case of hazardous materials, the disposal practices are not so casual, and the sites or methods of disposal are more carefully chosen.

The percentage recovery of fluids leaked or spilled is quite variable from state to state. In Mississippi, almost 43 percent of the hydrocarbons was recovered whereas in South Carolina, only 17 percent was recovered. The reasons for such a variation throughout the Southeast may be attributed to various factors, including: 1) individual state attitudes toward and responses to cleanup (for example, training and funding); 2) geology favoring rapid or slow infiltration or runoff to streams; 3) topography hindering cleanup or favoring leaks and spills; 4) attitude of the public toward reporting leaks and spills, and 5) lack of a central agency to which citizens can report.

The North Carolina Department of Natural and Economic Resources, Environmental Management Division, has a rather thorough program of describing petroleum product spills and leaks. Data have been collected that are useful in determining the probable final repository of the fluids that were lost to the environment. Basically, the fluids enter surface-water bodies and are partially recovered, or they are spilled on the ground and remain there. In some cases, the contaminated soil was disposed of in a landfill, or the contaminant was burned. Table 38 is a summary of the data and shows the number of incidents of leaks or spills that affected the surface-water or ground-water system. Out of a total of 120 reported incidents, cleanup operations were

Table 36. ESTIMATED VOLUME OF HYDROCARBONS SPILLED OR LEAKED AND RECOVERED IN THE SOUTHEAST IN 1975.[59]

	Alabama	Florida	Georgia	Mississippi	N. Carolina	S. Carolina	Totals
Number of Incidents	68	36	73	66	115	65	423
Total Volume Litres (Gallons)	456,944 (120,725)	173,887 (45,941)	420,582 (111,110)	247,312 (65,340)	377,671 (99,781)	480,240 (126,882)	2,156,644 (569,787)
Volume Recovered Litres (Gallons)	92,146 (24,345)	32,430 (8,568)	130,639 (34,515)	105,590 (27,894)	80,839 (21,355)	81,465 (21,523)	523,106 (138,205)
Volume Lost to Surface Water Litres (Gallons)	71,707 (18,945)	40,405 (10,675)	127,858 (33,778)	92,823 (24,524)	61,889 (16,351)	12,755 (3,370)	407,429 (107,643)
Volume Remaining on the Ground Litres (Gallons)	293,091 (77,435)	101,052 (26,698)	162,093 (42,825)	48,891 (12,917)	234,954 (62,075)	386,028 (101,985)	1,226,109 (323,939)

Table 37. ESTIMATED VOLUME OF HAZARDOUS MATERIALS SPILLED ON GROUND AND RECOVERED IN THE SOUTHEAST IN 1975.[59]

	Alabama	Florida	Georgia	Mississippi	N. Carolina	S. Carolina	Totals
Number of Incidents	6	4	7	3	11	8	39
Total Volume Litres (Gallons)	399,704 (105,602)	77,797 (20,554)	69,171 (18,275)	57,532 (15,200)	184,159 (48,655)	213,020 (56,280)	1,001,383 (264,566)
Volume Recovered Litres (Gallons)	1,041 (275)	None	563 (150)	37,850 (10,000)	102,195 (27,000)	1,136 (300)	142,785 (37,725)
Volume Lost to Surface Water Litres (Gallons)	1,238 (327)	204 (54)	18,263 (4,825)	757 (200)	47,123 (12,450)	48,637 (12,850)	116,222 (30,706)
Volume Remaining on the Ground Litres (Gallons)	397,425 (105,000)	77,593 (20,500)	50,341 (13,300)	18,925 (5,000)	34,841 (9,205)	163,247 (43,130)	742,372 (196,135)

Table 38. PETROLEUM PRODUCT SPILLS AND LEAKS IN NORTH CAROLINA IN 1974.[68]

Sources	Total Number of Incidents	Total Volume Litres (gallons)	Incidents of Surface Water Contamination	Incidents of Ground-Water Contamination	Incidents of Surface-Water and Ground-Water Contamination
Pipeline Rupture	26	78,115 (20,638)	8	14	4
Tank Overfill	24	549,351 (145,139)	12	11	1
Tanker Truck Accidents	39	386,100 (102,000)	21	17	1
Ruptured Tank	8	58,194 (15,375)	4	1	3
Dumping	2	757 (200)	2	—	—
Miscellaneous	17	58,490 (15,453)	12	4	1
Unknown Causes	4	21,234 (5,618)	2	1	1
TOTALS:	120	1,152,241 (304,423)	61	48	11

undertaken in 108 cases. However, other than burning of the flammable fluids and removal of the larger spills for recycling, most of the cleanup materials were probably disposed of in local landfills or buried on-site. Gasoline was often washed off the road surface by the local fire department.60) The data presented in the table indicate the main causes of the incidents and put emphasis on the need for bettering controls on petroleum product transfers, devising better inspection procedures, and developing tanks that are less likely to rupture in vehicular accidents.

Case Histories

The number of incidents of ground-water contamination due to spills and leaks, especially of petroleum-related products, is too great for each one to be described, and the information obtained in this study indicated that the problem was common throughout the region. During the investigation, a total of 27 water-well drilling contractors were personally contacted in the states of the study area. The largest number of well replacements was attributed to contamination by petroleum products. A total of 55 wells were replaced by 15 water-well drillers. For the most part, cases of contamination were reported to local or regional authorities. However, in some instances, no reports were made of the problem to any governmental or regulatory agency.9)

Conceivably, a large number of ground-water contamination incidents are buried in the literature or are undocumented. If the problem is not reported, it cannot be investigated, and if not investigated, no remedial actions can be taken to alleviate the situation and protect water users in the vicinity. The following are some case histories of petroleum product contamination caused by leaks and spills in the region.

A well used for fire-fighting purposes at a fire house in Franklin, Georgia, had to be replaced because it contained a high level of hydrocarbons and was considered unsafe for its intended use. The source of the contaminant is attributed to leaking tanks and/or spills.61)

In Morganton, Georgia, gasoline leaking from a buried storage tank caused an explosion which destroyed a well house. Two nearby wells reportedly yielded water containing so much fuel that it could be used to power tractors.61)

Residents of a small town near Atlanta, Georgia, noticed an objectionable taste and odor in their water. An investigation revealed that gasoline leaking from a buried storage tank had migrated down through fractured rock and into the town well.62)

At a power plant in east central Georgia, a pipe ruptured during cold weather and released approximately 2,271,000 l (600,000 gal) of No. 2 diesel oil. The spill was contained in an unlined dike around the facility. A total of 757,000 l (200,000 gal) were immediately recovered and 182,000 l (48,000 gal) were retrieved from sumps constructed for that purpose. It is assumed that the balance, amounting to 1,332,000 l (352,000 gal), remains in the ground-water environment. Investigations and recovery attempts are still being conducted at this site; no water-supply wells to date are reported to be contaminated because of this spill.63)

For about 40 years, two service stations in Fincastle, Virginia, had disposed of waste oil and gasoline on the ground. A fire occurred in 1974, and shortly thereafter, a private water well 30 m (100 ft) deep was contaminated by hydrocarbons, possibly as a result of the flushing action that took place in the ground when large amounts of water were applied to combat the blaze. Eventually, 13 to 18 domestic wells were rendered unusable.64)

In 1961, regular grade gasoline of 89 to 92 octane began seeping into manholes and ductlines of the Savannah Electric and Power Company in Savannah, Georgia. The gasoline was found in a very fine sand just above the water table over an area of approximately 4,830 sq m (52,000 sq ft). The amount of gasoline in the area was estimated to be 189,000 l (50,000 gal). Small, shallow wells were unable to recover the gasoline by direct pumping. However, deeper wells with a large pump were used to increase the water-table gradient and recover part of the gasoline. Complete recovery of the gasoline is not likely because of retention in the pores of the fine sand. Unsuccessful attempts were made to determine the source of the gasoline by comparing its chemical analysis with analyses of gasolines from the various service stations in the area. Hydrostatic tests on underground storage tanks indicated a number of small leaks which were repaired.65)

In the vicinity of airports, contamination of ground water by aviation fuel is very common. For example, the maintenance base of a commercial airline was found to be contributing large amounts of hydrocarbons to the Biscayne aquifer near Miami, Florida. The area of contamination was estimated to be 133,800 sq m (1,440,000 sq ft) and the quantity of hydrocarbons floating on top of the water table was about 3,785,000 l (1,000,000 gal). Drainage ditches were constructed and shallow wells were installed as part of the clean-up program. By utilising the drainage ditches, recovery of 75,700 l (20,000 gal) of the contaminant was accomplished in the first year of operation. Contamination has not yet reached any water-supply wells.66)

In addition to the contamination of ground water by petroleum products, many other fluids are entering the ground by means of leaks and spills. The following selected case histories summarize a number of them.

At a nuclear power plant located 40 km (25 mi) south of Miami, Florida, leaks in the storage facility and spills of radioactive fluid have occurred. Leaks in the steel liner of one of two multi-story concrete radioactive waste storage structures were detected before the plant went into operation. Reportedly, the company did not repair the leaks because they considered them minor. Leakage from the second storage structure was discovered in late 1975. The liner not only leaked, but the radioactive cooling water seeped through a 1.2 m (4 ft) concrete wall. The flow from the first structure is 340 l (90 gal) per hour, whereas the flow from the second leak is slower and at times is only a seep. Repairs to the structures cannot be started until all of the spent fuel is unloaded and the structures drained. This may take several years.67)

A portion of the water collected from the leaky structures is treated to remove some of the radioactive material. It is then stored in a tank that must be cleaned periodically. During a cleaning operation in 1975, the radioactive material, primarily containing radioactive cobalt, was removed and stored in 208 l (55 gal) containers. Later, 3,330 l (880 gal) of liquid waste from the containers soaked into the ground when it was accidentally dumped into the wrong drain. The amount of radioactive cobalt was approximately 15 times that released from the plant in the first six months of 1975. Additionally, the water in the storage tanks becomes very hot and must be circulated for cooling purposes. In the past, the circulation was handled by one pump with no emergency backup pump. Early in 1975, a pump failed, and a mishap with an emergency pump resulted in the release of over 28,000 l (7,400 gal) of radioactive waste liquid. Approximately 11,360 l (3,000 gal) flowed through a doorway and soaked into the ground.67)

At a battery plant in Sumter, South Carolina, numerous spills and leaks of nickel sulfate and nickel sulfamate entered the water table and migrated 762 m (2,500 ft) to private wells. Water from a well in a trailer park contained a maximum of 210 mg/l of nickel; clothes washed in the water turned black. The suspected point of entry into the ground water was the plant's waste treatment pond. However, five monitor wells were installed and subsequent analyses did not detect any nickel in the ground water in the vicinity of the pond. The source is thought to be spills and leaks of nickel compounds, estimated to be in excess of 11,026 l (2,913 gal), on the land surface from ruptured barrels and pressure lines and from a barrel plater.68)

In Chesterfield County, Virginia, a company recycling auto batteries disposed of waste sulfuric acid on the ground; it then flowed into an unlined drainage ditch. Contamination was first noted when a man utilizing a well 61 m (200 ft) from the plant complained of burning his hands. An analysis of the well water showed the following concentrations of chemical constituents: nickel, 0.3 mg/l; zinc, 25 mg/l; copper, 1.1 mg/l; sulfate, 1,500 mg/l; and pH, 4.1. The acid is now routed to neutralizing tanks and lined evaporation lagoons.69)

High levels of arsenic have been found to depths of 2.1 m (7 ft) in soil and ground water near a chemical plant in Alexandria, Virginia, which mixed arsenic-containing chemicals until 1967. Concentrations as high as 27,700 mg/l have been found on the 0.4-ha (one-acre) plant site. The arsenic contaminated an estimated 8,640 cu m (305,000 cu ft) of soil. At present, paving over the contaminated material appears to be the favored solution.70)

Two wells in a municipal well field in Irondale, Alabama, were contaminated by hexavalent chromium in concentrations of 60 and 70 μg/l. The U. S. Public Health Service limit is 50 μg/l. The wells are constructed in limestone with casing and cement grout set to a depth of 55 m (180 ft). The suspected source of the contamination is spills from a chromium plating plant located 30 m (100 ft) from the well field. Chromium-bearing water probably moved along fractures in the rock.71)

Ethyl acrylate and non-chlorinated hydrocarbons have contaminated ground water in the vicinity of at least one chemical plant in Langley, South Carolina; major spills and leaks from transmission lines near the railroad unloading area appear to be the cause. Improper handling and cleaning of used chemical containers and failure to collect washdown waters from empty tank trucks are also contributing factors. Test wells in the area contained ethyl acrylate in concentrations of from 500 to 1,000 mg/l.72)

In Hopewell, Virginia, a plant producing the pesticide Kepone, an ant and roach poison, was shut down after workers developed illnesses producing such symptoms as slurred speech, nervousness, twitching eyeballs, liver damage, and loss of memory. Extremely high levels of Kepone were found in the town's sewage treatment plant and in sludge dumped into a nearby pond.73) Airborne contamination around and downwind from the plant occurred during the period of operation, and particulate matter settled out onto the ground. Most of the monitoring emphasis was placed on air and surface-water contamination.

A memorandum from the Virginia State Water Control Board indicates that ground water in several areas is contaminated and that it is likely that further investigations will reveal that the entire Hopewell area is contaminated with some amount of Kepone.74) The plant was shut down, disassembled, and eventually the rubble was buried in a plastic-lined landfill. However, unlined sewage lagoons, sludge-filled ponds, and city dumps or landfills all contain Kepone which may eventually enter the ground water. Additionally, as plastisizers in the liner volatilize, it will become brittle and rupture, causing further and continuing contamination.

The town well in Prentiss, Mississippi, showed a continual rise in chloride concentration from 21 mg/l in 1958 to 53 mg/l in 1965 and to 70 mg/l in 1969. Although these concentrations are considerably lower than the 250-mg/l recommended limit of the U. S. Public Health Service, the community looked into the matter and determined that the well was being affected by the front of a plume of brine from a pickle plant located 0.8 km (0.5 mi) from the well. Brine from the plant was periodically disposed of in a small stream and, in addition, considerable leakage from the plant's 120 brine vats was also reported. Surface water runoff at the plant contained concentrations of up to 3,550 mg/l chloride.75)

In Swanquarter, North Carolina, a water well was contaminated with DDT which had been spilled on the courthouse grounds while being issued to farmers. The well had to be abandoned, and a replacement well was drilled.61)

An indication of the rapidity of contaminant movement through solutionally enlarged openings in limestone comes from studies related to chloride contamination of a municipal well in Stevenson, Alabama. The suspected source of the chloride was an accidental discharge from a textile plant brine vat into a nearby drainage ditch. A 300,000-mg/l sodium chloride brine solution was dumped into the ditch as a tracer. Approximately 18 hours later, a sharp increase was noted in the chloride content of water from the municipal well, which was located 1,067 m (3,500 ft) from the ditch, demonstrating that the drainage ditch was hydraulically connected with the limestone aquifer supplying the well.(76)

Future Trends

Accidental spills are unavoidable in the storage and transportation of fluids, and it is likely that the number of new spills will continue to increase in the future. Increased protection of ground-water resources can be achieved by better handling of spills after they have taken place.

Time appears to be the most important factor in minimizing the contamination of ground-water supplies by accidental spills. If cleanup operations are carried out quickly, especially when hydrocarbons are involved, there is a chance either to remove much of the pollutant from the surface before it enters the ground or to excavate the affected soil before the pollutant reaches the water table. On the other hand, if action is taken only after a broad area of an aquifer is affected, containment or removal of the contaminated ground water is almost impossible.

Recognizing the importance of immediate attention to spills, Pennsylvania has adopted a regulation that requires individuals responsible for a spill to immediately notify the Department of Environmental Resources regional office. If ground water is threatened, the Regional Geologist attached to the state's Ground Water Section attempts to respond within two hours.(77) In this manner, a technical appraisal of the situation is made within a short period of time, and cleanup operations and assessment of damage can begin in a more orderly manner. Also in Pennsylvania, certain industries are required to adopt a Pollution Incident Prevention Program, which establishes a specific procedure for informing the state of spills or other major pollution problems. The programs established by the states within the study area are commendable, especially those of Georgia and North Carolina; however, all of the states need to place more emphasis on ground-water contamination prevention.

Certainly the Pennsylvania approach to this problem should be considered by other regulatory agencies throughout the country. Also, there should be more recognition and better understanding by the carrier and other industries of the need for reporting spills to the proper authorities.

Finally, guidelines should be developed for state and local highway personnel, railroad operators, and industrial plant managers defining such procedures as who should be informed of accidental spills and how to handle the incident initially.

As in the case of spills, ruptures, breaks, and leaks in buried tanks and pipelines are unavoidable, and contamination of ground waters near such facilities will be a continuing problem. Leakage from sanitary and storm sewers will continue because many of these systems are old, and it is doubtful that a major portion of the old leaky sewers will be replaced in the foreseeable future. Thus, even though the materials and the design and installation practices for new sewers have greatly improved, this source of ground-water contamination will remain an important factor to be considered in making decisions regarding the siting and construction of water wells.

More promising from the standpoint of ground-water protection is the greater scrutiny by public agencies of major petroleum pipeline projects because of new environmental laws. Before the pipeline is constructed, codes and regulations call for consideration of factors involving design and management of the system related to possible effects of leaks on the underlying aquifers. Oil pipelines must be equipped with special valving, and all connections are to be carefully inspected at the time of installation in order to minimize leakage from breaks or failures that might occur. Public supply and domestic wells are mapped along the route to determine the sensitivity of water supplies to possible contamination. The flow of fuel oil through the line is carefully monitored so that losses in product can be quickly discovered, and an emergency program is developed for containment and cleanup in the event of a leak.

Concern for environment will undoubtedly lead to better protection of pipelines and tanks against corrosion and to the use of materials such as clay and tar to line excavations for tanks and pipelines where leakage might affect nearby water wells. Most of these efforts are presently directed toward minimizing the possibility of fire, explosion, or the escape of toxic substances. However, the need for protecting ground-water resources is becoming well-recognized in the region because of the growing number of cases reported to state agencies each year concerning contamination of water wells from hydrocarbons.

Industry has long appreciated the ills associated with poor housekeeping, and a number of trade organizations such as the Manufacturing Chemists Association and the American Petroleum Institute have published manuals and educational booklets on the prevention and control of surface discharges.(78,79,80) Nevertheless, more controls are needed on practices that can lead to contamination of ground-water resources in the vicinity of industrial, commercial, and construction sites. Elimination of open discharges of wastes to the ground surface, paving and the control of runoff in areas susceptible to infiltration of pollutants, and maintenance of above-ground distribution systems are especially important and may require more attention from regulatory agencies. Traditional practices of dumping waste petroleum products at the point of use should be evaluated for their long-term effects on ground-water quality, and controls should be established if the problem is of great enough magnitude to justify regulation.

Research is most needed in the development of new methods for removing hydrocarbons from the ground-water reservoir. Abatement by pumping or ditching is widely used but is only partially effective. Other means for cleaning up petroleum-contaminated soils and aquifers have been suggested and should be further investigated. These include water-flooding techniques to better control and collect the body of fluid for more efficient removal; biodegradation of hydrocarbons by aerobic and/or anaerobic bacteria; and the use of chemicals to precipitate or immobilize the pollutant.

AGRICULTURAL ACTIVITIES

Contamination of ground water can occur from a number of activities associated with crop growing, horticulture, dairy farming, and cattle raising. Introduction of chemicals at the surface which eventually migrate to the water table and accumulation of salts in ground water due to irrigation practices are the principal causes. The effects are both local and regional, depending upon the sources of the contaminants.

The agricultural chemicals which pose a major threat to ground water are fertilizers and pesticides (including herbicides and insecticides). Fertilization is one of the few methods by which man can exert a major influence on the natural processes governing plant growth. In order to maintain adequate plant yields, the major nutrients (nitrogen, phosphorus, and potassium) must be replaced to compensate for the removal by a previous crop. Originally, fertilizers consisted of organic wastes--animal, human, and plant. More recently, fertilizers have been produced synthetically.

The use of synthetic fertilizers has grown severalfold during the past thirty years. The use of nitrogen in fertilizer has increased even more rapidly (nitrogen application rates per acre have increased more than those for phosphorus and potassium) because it generally stimulates crop yields to a greater degree. As a result, nitrogen applications in excess of the amounts removed by the crop are common. Nitrate, the oxidized form of nitrogen, is produced and accumulated in the soil regardless of the applied nitrogen form. It is soluble and does not interact with the soil, and therefore can migrate with percolating water and enter the ground-water system. The use of nitrogen fertilizers is involved in 30 percent of U. S. food production.

Fertilizer use is both a rural and urban practice. Not only are large quantities applied to crops, but fertilizers are popular in the suburbs to promote lawn and garden growth. According to recent studies, plants may store such excess nutrients during the growing season and release them to the soil during the non-growing season.[81,82] During the non-growing period, excess nitrate, associated with recharge from precipitation, is leached from soil into the ground water at high concentrations.

In a study in Florence, South Carolina, excessive application of nitrogen fertilizer increased the nitrate content in the shallow ground water and the sandy loam soils. Under test conditions, excessive fertilizer was applied on fallow plots that were maintained free of grass and weeds by disking the soil. Table 39 shows the results of ground-water sampling at each of four plots that received applications of nitrogen fertilizer in concentrations of 0, 112, 336, and 672 kg/ha (0, 100, 300 and 600 lb/acre).[83]

During the one-year study period, the nitrate-nitrogen (NO_3-N) content of the ground water gradually decreased, but some increase over the background levels persisted for a year or longer.[83] Unexplained is the fact that, except for one sample, the background content of nitrate (NO_3) in the ground water exceeded the U. S. Public Health Service limit of 45 mg/l NO_3 (10 mg/l NO_3-N). Apparently, nitrogen fertilizer from earlier crops had been leached from the control plot during the study.

At the time these studies were being conducted on the test plots, the nitrate-nitrogen content of 13 tile lines used to drain fields of soybeans, cotton, corn, and tobacco grown on similar soils was being monitored. These data are presented in Table 40 for comparison. Nitrogen fertilizer was applied

Table 39. NITRATE-NITROGEN CONCENTRATIONS IN WATER-TABLE SAMPLES FROM FOUR EXCESSIVELY FERTILIZED PLOTS IN FLORENCE, SOUTH CAROLINA.93)

	Nitrate Nitrogen Added June 23, 1971			
kg/ha	0	112	336	672
lb/acre	0	100	300	600
Date Sampled	NO_3-N Concentrations in Groung Water in mg/l[a]			
08/19/71	21	33	101	89
09/16/71	18	25	73	81
10/12/71	14	15	62	79
10/27/71	14	17	60	54
12/15/71	13	15	35	48
01/13/71	14	17	47	35
02/17/72	16	23	29	37
03/13/72	14	18	23	32
04/20/72	13	28	15	27
05/25/72	11	13	23	27
06/22/72	5	14	33	25

a) To convert mg/l NO_3-N to mg/l NO_3, multiply by 4.4.

Table 40. NITRATE-NITROGEN CONCENTRATIONS FROM TILE LINE EFFLUENTS IN ACTIVELY CROPPED FIELDS NEAR HARTSVILLE, SOUTH CAROLINA.[63]
(NO_3-N in mg/l)

Crop	Effluent Sampling Dates, 7/15/71 to 6/22/72									
	7/15	8/2	8/4	8/19	8/25	9/16	1/13	2/17	3/14	6/22
Cotton				6.9			8.6	17.9		4.9
Soybeans, Tobacco		.71	2.8	4.3	.28	.71	8.5	10.2	4.7	4.9
Soybeans, Tobacco				4.4		.76	7.8	13.2		4.9
Soybeans, Tobacco			1.6	4.5	.56	.62	8.1	14.2		4.9
Cotton, Soybeans		.56	1.8	4.1	.62		9.2	14.6		4.7
Cotton, Soybeans, Tobacco			4.8	3.5	.53	.58	9.6	14.2		4.6
Cotton			4.8		.56		8.4	14.2	5.8	4.7
Soybeans	.65		3.7	6.3	.53	.59	9.6	12.6	13.4	3.7
Soybeans		.76	4.6				9.4	16.7	11.1	4.8
Soybeans	.47		5.8	9.8	.21	.74	8.8	15.2		4.8
Corn			5.8	3.6	.35		8.4	14.9		4.7
Soybeans, Tobacco	.71		6.1	6.4			7.8	15.3	9.3	4.7
Soybeans, Tobacco			5.8	7.4			9.8	14.2		4.8
Average	.61	.68	3.87	5.20	.47	.65	8.65	14.80	8.70	4.70

to these fields at the following rates: cotton, 103 kg/ha (92 lb/acre); soybeans, 0 kg/ha (0 lb/acre); corn, 195 kg/ha (174 lb/acre); and tobacco, 81 kg/ha (72 lb/acre).[83]

There was a wide seasonal range of nitrate-nitrogen concentration in the tile drain effluent, with little difference in the concentrations from the various fields at any one period of sampling. The highest levels of nitrate-nitrogen occurred during the winter or non-growing season.[83] This observation agrees with those of F. E. Allison who states that "nitrogen recoveries in the crop under average field conditions often are no greater than 50 to 60 percent of that applied, even if immobilization is taken into account. The chief channel of loss in normal agricultural practice is probably leaching, which usually occurs chiefly in the fall and spring months."[84] This, combined with the result of the above studies, points to the potential regional impact of excessive fertilization practices.

Studies of Coastal Plain soils in North Carolina indicate that approximately one-half of the applied nitrogen fertilizer was not utilized by the crop. Nitrogen balances were measured for moderately well-drained and for poorly-drained soils to evaluate the effects of drainage on the unused nitrogen. In poorly-drained soils with high water tables, much of the leached nitrate is lost as gaseous nitrogen through denitrification, and approximately 14.6 kg/ha (13 lb/acre) of nitrogen are lost annually to surface water via subsurface drainage. In moderately well-drained soils, there is no significant quantity of nitrogen lost via denitrification, but approximately 45 kg/ha (41 lb/acre) of nitrogen are lost to surface water via subsurface drainage. In the case of moderately well-drained soils, half of the loss was through tile drains. The samples of water from the tile drains contained a nearly constant concentration of 15 mg/l NO_3-N (66 mg/l NO_3).[85]

Calculation of the nitrogen balance for the two fertilized Coastal Plain study sites is presented in Table 41. The data indicate that, in moderately well-drained soils, approximately 12.5 percent of the nitrogen fertilizer applied at the rate of 160 kg/ha/yr (143 lb/acre/yr) will enter shallow aquifers. This amounts to approximately 20 kg/ha/yr (17.8 lb/acre/yr). There are reportedly 0.676 million ha (1.670 million acres) of well-drained cultivated land in North Carolina.[85] Thus, assuming the same application rates of fertilizer nitrogen, a total of 13,520 tonnes (15,142 tons) of nitrogen are entering the shallow aquifers each year. Similar data can be generated for other states if the application rates and the area of cultivated well-drained soils are known.

Table 41. NITROGEN BALANCE FOR THE TWO FERTILIZED NORTH CAROLINA COASTAL PLAIN STUDY SITES (Two Year Average).[85]

	Lenoir County Site (Moderately well-drained soils)		Beaufort County Site (Poorly-drained soils)	
	kg/ha/yr	lb/acre/yr	kg/ha/yr	lb/acre/yr
N Input				
Fertilizer	160	142.8	196	174.9
Net N from soil	0	0.0	0	0.0
Total	160	142.8	196	174.9
N Removal				
Grain	92	82.1	92	82.1
Surface runoff	22	19.6	29	25.9
Subsurface drains	26	23.2	15	13.4
Total	140	124.9	136	121.4
Nitrogen not directly accounted for	20[a]	17.9	60[b]	53.6

a) Data indicate that most of this N moves into shallow aquifers.
b) Data indicate that most of this N is lost by denitrification.

In a three-year study conducted near Tifton, Georgia, nitrogen fertilizer applied to test plots planted in corn moved rapidly through the loamy sand soil to the shallow ground water. Before the application of 128 kg/ha (114 lb/acre) of nitrogen fertilizer and a sidedressing of 168 kg/ha (150 lb/acre) of liquid ammonium nitrate-urea each year, the fields had been fallow for four years. The tile drainage water prior to the start of the study had a concentration of 4.8 mg/l NO_3-N (21 mg/l NO_3). The tile drain effluent nitrate-nitrogen concentration rose to 7.1 mg/l (31 mg/l NO_3) in the first year, 10.3 mg/l (45 mg/l NO_3) in the second year, and declined to 9.4 mg/l (41 mg/l NO_3) in the third year.[86] The vertical movement was restricted below a depth of .92 m to 2.14 m (3 to 7 ft) by a zone of low permeability in the Hawthorn Formation. Nitrate-bearing water moved along the upper surface of this zone, which slopes 3.2 percent. Although nitrate in the ground water usually moved laterally through the permeable loamy sand toward streams, there is the potential for movement through sandy horizons of the formation to domestic wells tapping this aquifer.[87] However, the potential for contamination is not as great as in areas underlain by more permeable rocks.

The term pesticides is a general term for that group of chemicals used to control organisms which limit crop growth or proliferation; it usually includes algacides, herbicides, fungicides, and insecticides. The problem with the use of pesticides is similar to the one involving use of nitrogen fertilizers; that is, some chemicals are not easily degraded in the natural environment. There are many pesticides on the market that are readily degraded and are, therefore, less of a threat to ground water. Pesticide contamination of ground water is less common than nitrate contamination. Pesticides are usually applied in limited quantities a few times a year. However, handling practices, such as mixing in the fields, increase the possibility of spillage and contamination.

A journal article reported that the ability of arsenic as MSMA (monosodium methanearsonate) to move through soils in Alabama is directly dependent upon the type of soil. Silt loams adsorbed considerably more MSMA-arsenic than fine sandy loams or loamy sands. The high adsorption on the silt loams is explained by the high kaolinitic percentage of the clay fractions, the clay content of the soil, and the high free iron content. These characteristics are lacking in the fine sandy loams and loamy sands, which also have a coarse siliceous nature. Relative arsenic concentrations in successive increments of effluent from glass columns packed with the different soils showed that the loamy sands retained the least and the silt loams retained the most.[88]

Along these same lines, research was undertaken on the movement of picloram, an extremely potent herbicide used for control of perennial broadleaved plants in non-cropland areas. Its migration through the soil solum was compared with that of nitrate; leaching was conducted on field plots of loamy sand and fine sandy loam in Alabama. The results show that: (1) the nitrate moved downward in both of the soils at a rate of about one inch per one inch of rainfall received; (2) some picloram was retained in surface soil whereas all nitrate was eventually leached below the surface soil; and (3) the picloram that was leached below the surface soil moved downward at about the same rate as nitrate.[89)]

The above studies indicate the potential of insecticides and herbicides to move into the ground water. Consistently, researchers will emphasize that these contaminants are adsorbed on clays in the soils. Yet, many types of soils of the U. S., and especially some of those found in the Coastal Plain of the Southeast, are often lacking in sufficient clay content to favor adsorption. Proof that clays will adsorb the pesticides and herbicides does not mean that the user of these products has soil suitable for such a process to take place.

Many persons conducting investigations of the potential movement of contaminants from a source make the fundamental error of locating observation wells such that representative water samples are not obtained. For example, one study of the movement of various pesticides in soil, surface water, and ground water concluded that no detectable levels of these pesticides were found in well water. These conclusions were correct; however, the wells were sited upgradient from the test plots and contaminants were moving away from them. This type of situation occurs very frequently, and once test results are reported in the literature, they are used as a guideline by others and the error is compounded. The need for a team effort involving various disciplines on such studies is evident.

Investigations in South Carolina in 1971 showed that the insecticides toxaphene and fluometuron, when applied to the soil surface, were found in the ground water within two months. About two million kg (4.4 million lb) of toxaphene and about 70,000 kg (154,000 lb) of fluometuron were used in 1971. Even after the growing season ended, these insecticides persisted as residues and were present throughout the duration of the study.[90)]

Although an increase in insecticide or herbicide content on a regional basis has not been documented, it undoubtedly does occur in the vicinity of large farms underlain by permeable soils. Knowledge of the amounts and types of pesticides used in the Southeast will be useful if agricultural patterns are known. A 1970 summary of sources of pesticides in Florida waters was prepared for use in designing programs to monitor and trace them in the hydrobiologic system.

Figure 35 is a map of major citrus and agricultural areas in Florida (1966). There are several hundred different organic pesticides manufactured, but only 22 different kinds appear in significant quantities in Florida waters because they are associated with specific crops. The chlorinated hydrocarbon Chlorobenzilate and the organophosphates Delnab, Ethion, Systox, Trithion, and Tedion are found most commonly in citrus-growing regions. Table 42 lists pesticides commonly used in 1966 to control major citrus and vegetable pests in Florida.

Dyrene, Maneb, Zineb, and Karathane are fungicides largely used in vegetable farming; environmentally persistent chlorinated hydrocarbons such as DDT, Dieldrin, and Toxaphene are also used on vegetables.

Table 43 lists estimated amounts of common pesticides used in Florida during 1966 according to area of application. Compiling such data in a more detailed form by individual county and type of vegetable crop (Table 44) would be helpful in assessing impacts on ground-water quality and should point to areas of research.[91]

One problem occurring with great frequency is the contamination of ground water and wells by pesticides applied to the foundations of residences and other structures as part of termite and other insect control programs. This situation is in need of greater assessment and regulation. Health officials interviewed during this study expressed considerable concern with pesticide application methods and the qualifications and training of people engaged in this business. Some felt that stricter controls were needed.

Case Histories

Rising concentrations of arsenic in two wells in Broward County, Florida, are attributed to the use of sodium arsenite weed killer and the subsequent movement of arsenic through the drainage canal system from industrial or agricultural sources. Drought conditions limited the

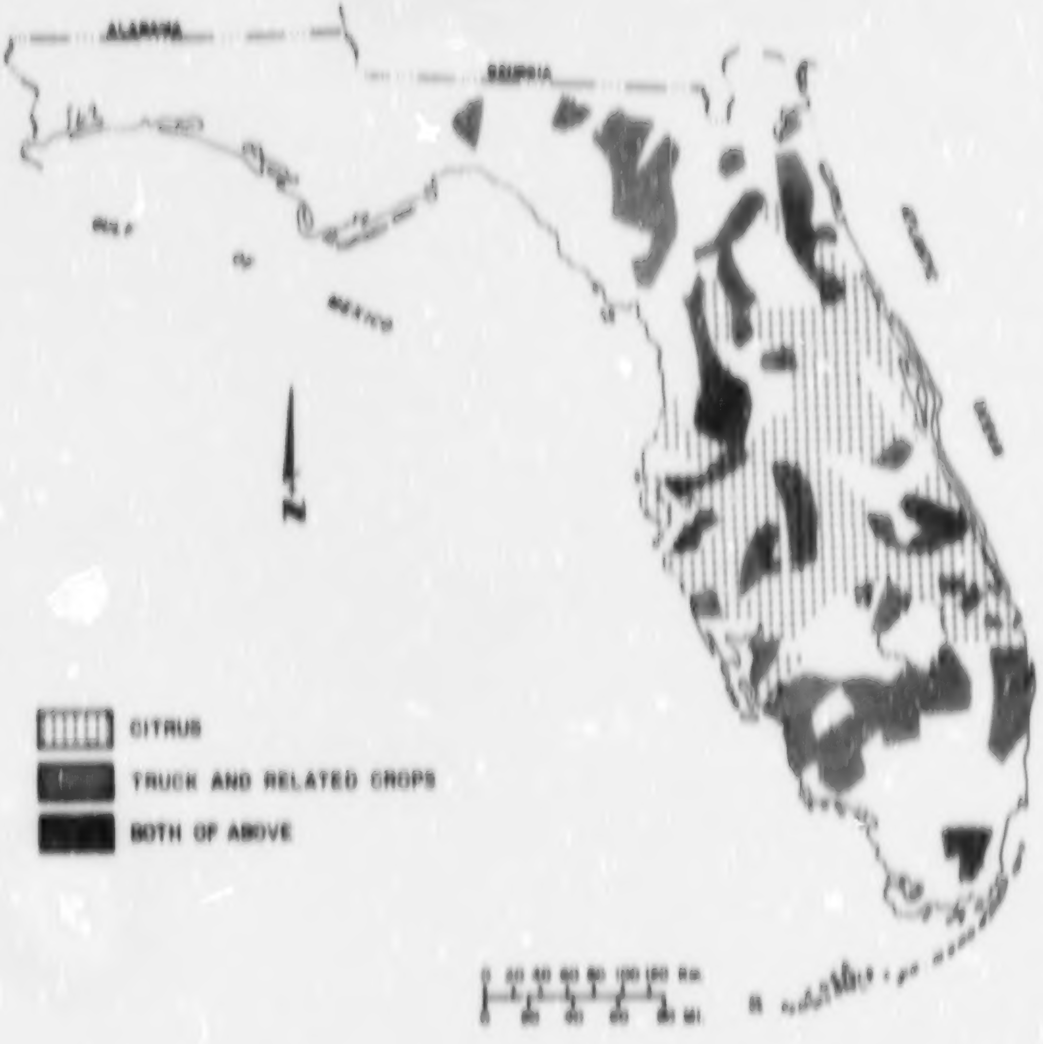

ALABAMA
GEORGIA
GULF OF MEXICO
ATLANTIC OCEAN
N
CITRUS
TRUCK AND RELATED CROPS
BOTH OF ABOVE
0 20 40 60 80 100 120 Km
0 20 40 60 80 Mi

Figure 35. Major citrus and agricultural areas in Florida, 1966.91)

Table 42. ORGANIC PESTICIDES COMMONLY USED IN 1966 TO CONTROL MAJOR CITRUS AND VEGETABLE PESTS IN FLORIDA.[91]

Major Pests	Pesticides Applied for Control
	Citrus
Fungi	Captan
Rust Mites	Chlorobenzilate, Zineb
Scale Insects	Ethion, Guthion, and Parathion
Spider Mites	Delnab, Ethion, Tedion, Trithion, Kelthane, Systox
	Vegetables
Aphids	Dimethoate, Parathion, Phosdrin
Armyworms	DDT, Parathion
Bean Leafhoppers	Toxaphene
Bean Leafrollers	Guthion, Toxaphene
Bud Nematodes	Parathion
Cabbage Loopers	Parathion, Phosdrin
Corn Earworms	Sevin, Toxaphene
Cowpea Curculio	DDT, Toxaphene
Fungi (including Leaf Blights, Leaf Spots and Mildews)	Captan, Dyrene, Karathane, Maneb, Nabam, Zineb Guthion, Parathion
Leaf Miners	Parathion
Pameras	Kelthane
Spider Mites	Sevin
Stinkbug Worms	Dieldrin
Sweet Potato Weevils	Diazinon, Dimethoate, Parathion
Wireworms	

Table 43. ESTIMATED AMOUNTS[a)] OF COMMON PESTICIDES USED IN FLORIDA DURING 1966.[b)] [91)]

	Millions of Kilograms (Pounds) Applied[c)]		Percent of Total Usage by Crop
Vegetable and melons	8.8	(19.4)	57
Citrus	2.8	(6.2)	18
Lawns and homes	1.6	(3.5)	10
Soybeans, cotton and peanuts	1.5	(3.2)	9
Mosquito control	0.7	(1.5)	5
Sugar Cane	0.1	(0.2)	1
Totals	15.5	(34.0)	100

a) Totals include usage of the major chlorinated hydrocarbon, organophosphate, carbamate, and metallo-organic pesticides only. Herbicides, inorganic compounds and other categories of pesticides have been omitted from these tabulations.

b) Usage of pesticides for all categories is given for calendar year 1966 rather than for crop years, which vary for different agricultural crops.

c) Active ingredient.

TABLE 44.- AMOUNTS OF PESTICIDES APPLIED TO VEGETABLE CROPS IN DADE COUNTY FOR THE CONTROL OF INSECTS, MITES, NEMATODES, AND FUNGI, JULY 1, 1966–JUNE 30, 1967.[illegible]

		Percentage use of each chemical by crop															
Crop	Percentage of total hectares[a] (acres)	Chlorinated hydrocarbons			Organophosphates						Carbamates and metallo-organic fungicides						
		DDT	Dieldrin	Toxaphene	Parathion	Guthion	Dimethoate	Phosdrin	Diazinon	Kelthane	Sevin	Dyrene	Nabam	Maneb	Zineb	Captan	Karathane
Tomato	38				39	66	48				78	100	100	51			
Pole beans	20				22	25	18	77						14			
Irish potato	17				16	7	34		100					28			
Squash	6				10	7									70		39
Sweet Corn	6	97		93							22			6			
Cucumber	6				6	4									6		39
Sweet Potato	2		100														
Southern pea	2	3		7													
Other crops[b]	5				9	1		23		100				1	16	100	22
Total of each insecticide (active ingredient) applied in thousands of																	
Kilograms		35.4	2.7	55.3	48.5	66.2	5.5	1.3	6.00	0.8	41.0	18.0	358	204	17.8	63.5	36.2
Pounds		78	6	122	107	146	12.2	2.9	13.2	1.8	90.4	39.6	790	450	39.3	140	79.8

a/ Total hectares (acres) planted in Dade County 18,616 (46,000).

b/ Cabbage, collard, turnip, cantaloupe, watermelon, okra, and strawberry.

dilution and flushing of the arsenic from the canals, and pumping at the well fields induced movement of the arsenic from the canals into the aquifer. The Broward County Health Department has restricted the use of arsenite weed killers in the vicinity of public supply wells in the county.[92]

In Durham County, North Carolina, pesticides were found in the water samples obtained from two domestic supply wells drilled in crystalline rock. The foundations of two houses located 45.7 m (150 ft) apart had been treated with chlordane. The well for one of the treated houses, situated downgradient, was contaminated. Movement of contaminated water along the outside of the well casing was suspected as the cause. The second well supplied a third untreated house located 45.7 m (150 ft) further downgradient. The suspected cause in the latter case was the migration of the contaminated water through the rock fractures.[93]

A similar case occurred in Middletown, Virginia, where six cases of pesticide poisoning were reported to have been caused by well water contaminated during termite protection. Chlordane (0.29 mg/l) was found in the well water.[94]

A strange taste in the water from a recently completed well in the Coastal Plain deposits near Statesboro, Georgia, was found to be caused by the presence of the pesticides toxaphene and DDT, which were in soil used to backfill around the well casing. The backfill material had been obtained in the vicinity and was contaminated by flushings from an insecticide sprayer. Concentrations of the contaminant were small because of the very low solubilities of the pesticides. However, much of the pesticide is suspected to still be in the backfill material.[95]

A damage suit was brought against a pest-control company in Virginia as a result of chlordane contamination of domestic wells. The chlordane was injected through the cement basement floor of a house. The following day, chlordane appeared in the water well adjacent to the house. Attempts to cleanse the well by continuous pumping proved futile. Several months later, a new well was drilled approximately 30 m (100 ft) from the house. The new well was also contaminated with chlordane. After one year of periodic pumping and sampling, the chlordane content is now below three μg/l and the new well is being used.[96]

Contamination of a well by telone, a soil fumigant, occurred in Benson, North Carolina. The well is 6.1 m (20 ft) deep with a concrete slab 1.8 m (6 ft) in diameter poured around it and grouted to a depth of 3 m (10 ft) as prescribed by

North Carolina State Board of Health regulations. It is unknown whether the contamination is due to nearby application on crops or to an accidental spillage into the well.93)

A domestic well near Smithfield, North Carolina, was contaminated with a mixture of Ethyl Parathion, TDE, Xylene, and MH-30 (pesticides used for tobacco sucker and insect control) when a pipe discharging into a sprayer tank was accidentally disconnected and the contents siphoned onto the ground. The fluid contaminated the shallow well and the odor was noticed that night while family members were showering. The well was abandoned, and a deeper well was constructed away from the contaminated area.93)

Since 1969, the North Carolina Division of Health Services has conducted a pesticide detection program; approximately 100 wells have thus far been found to be contaminated with pesticides. In the first 11 months of 1975, 36 well-water samples were collected for pesticide analysis (on the basis of suspicions of the well owners); the analyses were positive in 15 of these wells. The pesticides detected were Toxaphene, Chlordane, Prophos, Aldrin, 2-4-D, and Atrazine. The most common causes of contamination were applications of pesticides around house foundations or spills around wells.93)

In 1969, a systematic study of individual water supplies in four counties in Georgia was conducted to assess the number of wells contaminated by various substances and to determine what geologic or physical factors favored contamination. Pesticide analyses were run on 76 water samples obtained from shallow wells. Pesticides were detected in low concentrations in 43 of the samples. Surface contamination was considered to be the source; DDT was the predominant pesticide detected.96)

Contamination of the shallow unconfined aquifer by chlorides contained in irrigation waters is occurring in southwest Florida. In that area, the Floridan Aquifer contains water under pressure with heads ranging from about 20 ft above msl along the coastal margin to more than 50 ft above msl in the interior. Wells drilled into this aquifer will flow at the surface over most of the area and are utilized for irrigation purposes. The chloride content of this water averages about 1,000 mg/l. Although the water is used to irrigate salt-tolerant crops, an excessive amount is applied. The excess percolates downward to the water table, causing an increase in chloride concentrations in the unconfined aquifer. Additionally, some of the water flows out of the area through surface drainageways to points where the shallow aquifer is used extensively.97)

The use of saline artesian water for irrigation has contaminated the shallow unconfined aquifer in Brevard County, Florida. In the northern part of the county, along the west side of the Indian River, citrus areas are irrigated with artesian water containing as much as 1,800 to 2,000 mg/l of chloride. Some groves have been badly burned and even killed by over-irrigation with salty artesian water.[98] Because the Floridan Aquifer water is highly mineralized in Brevard County, water for domestic and commercial uses is pumped from the shallow aquifer which is the sole potable source.[99]

A potential source of ground-water contamination is the mass burial of livestock, although no actual case histories have been reported. In five adjoining counties in south central Mississippi, it was necessary to kill and bury 10 million chickens after discovering that feed sold in these counties was contaminated with the pesticide Dieldrin. Burial sites in the five counties were selected in areas underlain by clay, to prevent ground-water contamination. The chickens were placed in trenches 2.4 to 3.0 m (8 to 10 ft) deep with 1.2 m (4 ft) of cover on top. No monitor wells were placed around the sites to determine whether movement of the decomposition products toward ground water was taking place. It is reported that the decomposition in the unvented burial trenches was so intense that chicken bodies would erupt through the soil with explosive sounds.[100]

An additional source of ground-water contamination in the Southeast is that resulting from animal-holding operations such as feedlots. Another is seepage from unlined lagoons containing solid and liquid dairy cow or hog waste. The problem of potential ground-water contamination from these sources has been recognized but has not been fully assessed.[101]

It is common practice in northwest Alabama to hold liquid and solid dairy wastes in lagoons constructed by a combination of excavation and diking. One lagoon of this type, with a clayey chert gravel bottom, leaked large quantities of liquids, manure and sludge to a spring located approximately 300 m (1,000 ft) downgradient. The leak occurred when a small sinkhole opened in the side of the lagoon. The spring served as a domestic water supply.[102]

An assessment of ground-water contamination potential from anaerobic lagoons treating wastes from milking barns was made at a Florida dairy. Test wells located 5 m (16.4 ft) and 15 m (49.2 ft) from a 4-m (13.1-ft) deep anaerobic lagoon indicated significant increases in biochemical oxygen demand, total dissolved solids, and nitrate-nitrogen after eight months of operation. No contamination was detected at a 30-m (100-ft) deep test well during this period.103) It was also noted that the infiltration rate at the site did not decrease to a constant value, as might be expected if sealing of the lagoon had occurred through organic clogging but fluctuated with time.104)

A study of 21 feedlots in Georgia concluded that contamination of the ground water directly beneath the sites is probably not significant because of the high level of denitrification due to extended wet soil conditions. The data indicate that the average soil nitrate-nitrogen content in the upper 15 cm (6 in.) was less than 20 mg/kg (88 mg/kg NO_3).101) However, cattle feedlots can become a source of local ground-water contamination after abandonment of the site when nitrogen compounds are leached out and converted to nitrates. It must also be pointed out that in the above study no samples of ground water under the site were taken, only soil cores to depths of 122 cm (4 ft).

It has been noted elsewhere that comparatively high nitrate concentrations occur under feedlots. The nitrate-nitrogen content of ground water at depths of 4 to 11 m (13 to 36 ft) under Colorado feedlots ranged from 1.1 to 21 mg/l (4.8 to 93 mg/l NO_3).105) Studies in Missouri showed that, in old abandoned feedlots, the highest concentrations of nitrate in the soil were 1.8 to 3.7 m (6 to 12 ft) below the surface, while in-use lots contained the greatest quantities of nitrate in the surface layers of the soil.106,107) Nitrate-nitrogen concentrations as high as 16.7 mg/l (73 mg/l NO_3) were noted in ground water around feedlots in the Texas Panhandle.108)

During the period 1950-1970, the quantity of commercial fertilizer used in the southeast dropped from 39.7 percent of the total U. S. consumption to 22.8 percent. There are indications that the amount used will continue to decline as a result of industrialization in the Southeast. Lands are going fallow because of worker migration to the cities, lands are being removed from cropping because of government cash subsidies, crop yields are being increased due to better farming methods, and farmlands are being converted to urbanized areas. Table 45 presents fertilizer consumption data for the Southeast during the period 1950-1974.

It is expected that there will be an increased use of fertilizers, insecticides, and herbicides by home owners in suburban areas. Research is needed on the effect of this

Table 45. QUANTITIES OF COMMERCIAL FERTILIZERS[a] CONSUMED IN THE UNITED STATES BY STATE,[109] IN THOUSANDS OF TONNES (Thousands of Short Tons).

STATE	COMMERCIAL FERTILIZER 1950[b]	 1960[b]	 1970[b]	 1974[b]
United States	16,426,754 (18,092,922)	22,361,594 (24,632,732)	35,797,742 (39,433,512)	42,005,413 (46,332,599)
Alabama	1,034,606 (1,139,773)	974,735 (1,073,733)	937,786 (1,033,032)	1,032,801 (1,137,697)
Florida	797,008 (877,955)	1,414,873 (1,558,574)	1,717,008 (1,892,364)	1,743,381 (1,920,446)
Georgia	1,078,499 (1,188,036)	1,371,079 (1,455,253)	1,675,529 (1,845,703)	2,008,746 (2,210,560)
Mississippi	581,543 (640,607)	629,572 (693,514)	671,453 (739,640)	876,665 (965,700)
North Carolina	1,579,888 (1,740,368)	1,455,124 (1,602,913)	1,620,988 (1,785,622)	1,862,992 (2,052,205)
South Carolina	793,807 (874,520)	711,663 (783,941)	775,736 (855,625)	876,066 (965,043)
Virginia	661,154 (728,304)	680,518 (749,636)	749,728 (825,873)	729,007 (803,046)
TOTALS	6,526,675 (7,189,551)	7,187,564 (7,917,564)	8,149,108 (8,977,068)	9,127,655 (10,054,699)
% of U.S. Use	39.7	32.1	22.8	21.4

a) Includes government sales of fertilizer: secondary and micronutrient fertilizers (those essential to plant growth other than nitrogen, phosphate, and potash), but not liming materials.

b) Year ended June 30.

contamination sources on ground-water quality, especially where expanding cities are surrounding the sites of wells supplying them.

MINING ACTIVITIES

Mining operations, such as ore extraction, beneficiation methods, generation of wastes, and dewatering practices, are among the most obvious causes of ground-water contamination. Additionally, two widespread types of ground-water contamination resulting from mining activities stem from acid mine drainage and leaching of mine tailings. In both these cases, the contaminants are released from the mineralized rocks because they are not stable in the new chemical environment resulting from dewatering of mines or from disposal of mineralized wastes on the land surface. The large affected areas usually associated with mining activities and the variability of geologic conditions make recovery of the contaminants or the prevention of the release of the contaminants a difficult task.

The numbers and sizes of mines in the Southeast are not known in detail. Mining has been an active industry in the region for more than 200 years, and mines abandoned prior to the present century have probably been forgotten, even by local historians. Data on the amount of land disturbed by surface mining as of January, 1974, are given in Table 46. Information on the amount of land disturbed by earlier mining activities by state and by mineral commodity is given in Table 47.

Mines in the Southeast are of two basic types: surface mines and underground mines. Some solution mining has been utilized, but to a very limited extent. In any mining method, the presence of ground water can make ore extraction impossible if the water cannot be removed. Dewatering is a time-consuming and expensive operation occurring prior to and during the actual mining.

One effect of dewatering and thus lowering the water table is that mineralized rocks are exposed and oxidized. The oxidation of sulfide minerals is the principal cause of ground-water contamination near mining areas. The most common such mineral, pyrite (FeS_2), is usually associated with the ore and the country rock surrounding the ore body, as well as being present in coal deposits. Oxidation of pyrite in the presence of water results in the formation of sulfuric acid (H_2SO_4). Associated with the acid are high iron and sulfate. In the presence of the acid solutions, other materials may be dissolved from their mineral form and mobilized.

Table 46. STATUS OF LAND DISTURBED BY SURFACE MINING IN THE SOUTHEAST AS OF JANUARY 1, 1974, BY STATE, IN HECTARES (Acres).[120]

	Land needing reclamation							
	Reclamation not required by law			Reclamation required by law				
State	Coal mines	Sand and gravel	Other mined areas	Coal mines	Sand and gravel	Other mined areas	Land not requiring reclamation	Total land disturbed
Alabama	23,423 (57,878)	7,029 (17,369)	7,182 (17,747)	2,881 (7,118)	728 (1,800)	1,140 (2,816)	30,527 (75,432)	72,911 (180,160)
Florida	—	4,510 (11,144)	44,680 (110,402)	—	594 (1,467)	28,924 (71,472)	22,135 (54,694)	100,843 (249,179)
Georgia	—	520 (1,285)	5,981 (14,779)	—	455 (1,125)	5,028 (12,425)	3,539 (8,744)	15,523 (38,358)
Mississippi	—	13,974 (34,529)	4,075 (10,069)	—	—	—	353 (873)	18,402 (45,471)
North Carolina	—	4,816 (11,900)	1,943 (4,800)	—	1,497 (3,700)	2,104 (5,200)	2,833 (7,000)	13,193 (32,600)
South Carolina	—	3,440 (8,500)	4,856 (12,000)	—	—	—	6,071 (15,000)	14,367 (35,500)
Virginia	7,285 (18,000)	698 (1,725)	2,216 (5,475)	2,029 (5,014)	314 (775)	994 (2,455)	15,647 (38,664)	29,180 (72,103)
Totals	30,708 (75,878)	34,987 (86,452)	70,933 (175,272)	4,910 (12,132)	3,588 (8,867)	38,190 (94,368)	81,105 (200,407)	264,429 (653,371)

Table 47. LAND DISTURBED BY STRIP AND SURFACE MINING IN THE SOUTHEAST AS OF JANUARY 1, 1975, BY COMMODITY AND STATE, IN HECTARES (acres).[111]

State	Clay	Coal	Stone	Sand and gravel	Gold	Phosphate rock	Iron ore	All other	Total
Alabama	1,619 (4,000)	20,478 (50,600)	1,578 (3,900)	8,580 (21,200)	40 (100)	—	21,287 (52,600)	607 (1,500)	54,189 (133,900)
Florida	5,342 (13,200)	—	10,239 (25,300)	1,578 (3,900)	—	58,115 (143,600)	—	1,133 (2,800)	76,407 (188,800)
Georgia	526 (1,300)	121 (300)	2,752 (6,800)	486 (1,200)	—	—	40 (100)	4,856 (12,000)	8,782 (21,700)
Mississippi	1,093 (2,700)	—	162 (400)	10,725 (26,500)	—	—	12 (30)	—	11,991 (29,630)
North Carolina	2,347 (5,800)	4 (10)	2,428 (6,000)	7,446 (18,400)	890 (2,200)	121 (300)	40 (100)	1,619 (4,000)	14,897 (36,810)
South Carolina	4,411 (10,900)	—	567 (1,400)	4,209 (10,400)	81 (200)	3,278 (8,100)	40 (100)	648 (1,600)	13,234 (32,700)
Virginia	445 (1,100)	12,060 (29,800)	1,740 (4,300)	5,302 (13,100)	243 (600)	40 (100)	3,116 (7,700)	1,659 (4,100)	24,606 (60,800)
Totals	15,783 (39,000)	32,663 (80,710)	19,466 (48,100)	38,326 (94,700)	1,254 (3,100)	61,554 (152,100)	24,535 (60,630)	10,522 (26,000)	204,106 (504,340)

Acid water, pumped during mining or flowing from the mines as the water table rises after mining and dewatering operations cease, causes extensive damage to both surface and ground water. Also, acidic rainwater passes through oxidized sulfide minerals in the tailings or spoil piles, releasing large quantities of sulfuric acid. As shown in Table 48, acid mine drainage and mine-related sediment load affect fish and wildlife along more than 1,200 km (750 mi) of streams, of which 856 km (535 mi) are in Alabama and Virginia.

Dewatering of mines can also result in the movement of poorer quality water into the mining area; after the mine is abandoned, rising ground water of a significantly degraded quality can enter the dewatered portions of aquifers. Ground-water contamination is not generally taken into account in acid mine drainage studies, but it may be even more serious than contamination of surface waters.

A number of recent studies have treated the subject of radiological pollution from phosphate rock mining and processing in the phosphate district of south central Florida. Although the studies are still continuing because they are not yet definitive, analyses of samples of ground water collected in 1966 in the area showed radium concentrations as high as 76 pCi/l. A more detailed study, the results of which were released in 1973, pointed to the phosphate development and processing activities as the source of radium-226 in the ground water. In addition, the radon-222 found in houses built on recovered phosphate land was attributed to these sources.[112,113,114]

Phosphate rock is a term used in the mining industry to describe a rock containing economic quantities of phosphate minerals, usually calcium fluorophosphate. Figure 36 shows the locations of the principal phosphate mining and milling sites in the Southeast. In the Florida phosphate district, the phosphate has a sedimentary origin and occurs as minerals of the apatite group, represented by the formula $Ca_5(PO_4)_3(F,Cl,OH)$.

Uranium is associated with the phosphate as an impurity, and the amount varies directly with the phosphate content. There are 40 to 165 g (0.1 to 0.4 lb) per tonne (ton) of rock.[115] The decay chain of uranium-238 leads to radium-226 and radon-222. Radon-222, a gas, decays into particulates which can be adsorbed onto particles of dust that might be inhaled. Miners exposed to radon have an increased incidence of lung cancer, and the radium tends to replace calcium in bone.[116]

Table 48. FISH AND WILDLIFE HABITAT ADVERSELY AFFECTED BY STRIP AND SURFACE MINING IN THE SOUTHEAST, AS OF JANUARY, 1967.[111]

	Streams		Reservoirs & Impoundments		Wildlife Habitat
State	Kilometres (Miles)	Surface Hectares (Surface Acres)	Number	Surface Hectares (Surface Acres)	Hectares (Acres)
Alabama	440 (275	660 (1,700)	7	6,597 (16,300)	4,856 (12,000)
Florida	insignificant	insignificant	—	—	16,593 (41,000)
Georgia	296 (185)	206 (510)	10	158 (390)	324 (800)
Mississippi	48 (30)	77 (190)	1	121 (300)	769 (1,900)
North Carolina	—	—	—	—	344 (850)
South Carolina	—	—	—	—	324 (800)
Virginia	416 (260)	411 (1,015)	—	—	2,428 (6,000)
Totals	1,200 (750)	1,382 (3,415)	18	6,874 (16,990)	25,638 (63,350)

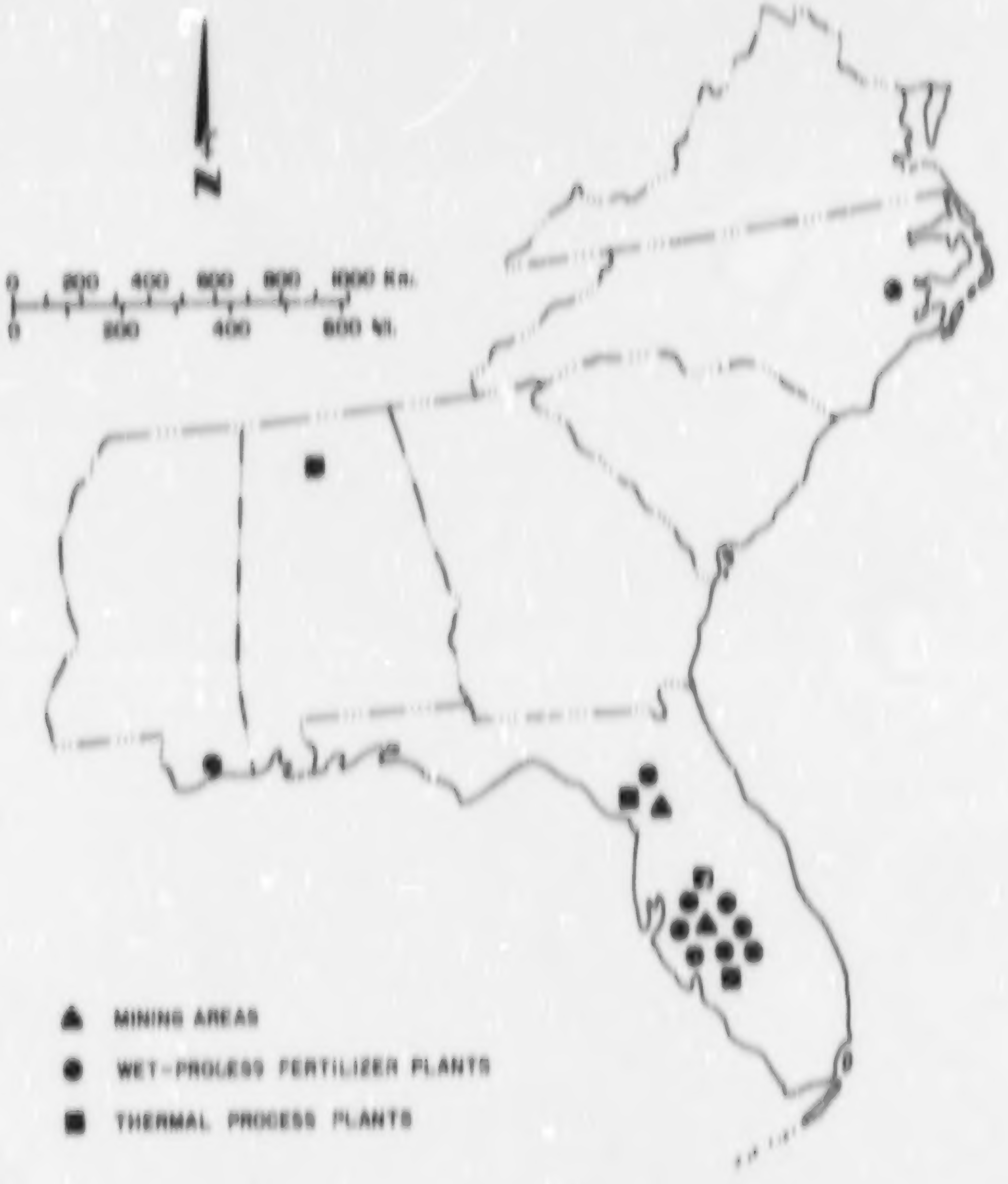

N
0 200 400 600 800 1000 Km.
0 200 400 600 Mi.
MINING AREAS
WET-PROLESS FERTILIZER PLANTS
THERMAL PROCESS PLANTS

Figure 36. Major phosphate rock mining and milling sites in the Southeast.112)

In the Florida phosphate region, the overburden is removed, the ore is mined with draglines, and the materials are then slurried and pumped to washing plants. Slimes, which contain particles less than 0.074 mm (0.0029 in) in size, are pumped back to mined-out pits or to surface ponds. Material containing particles larger than 0.074 mm (0.0029 in) is treated by an amine flotation process. The separated phosphate minerals are then sold for export or sent to a phosphate processing plant. The silica sand separated from the ore is discarded in piles, used in dike construction, or sent to mined-out areas. The used amine flotation water is discharged to mined-out areas and recycled.(112) Figure 37 shows the Florida phosphate rock mining and beneficiation flowsheet.

In Florida, the wet process is the most commonly used processing method, in most cases utilising sulfuric acid to produce phosphoric acid and a waste product of hydrated calcium sulfate (gypsum). Various investigators indicate that there is a partitioning of uranium and its decay products during the acidisation of the ground phosphate rock.(117,118,119) All of the uranium remains with the fertiliser, while a major portion of the radium and its decay products are removed in the waste, both liquid and solid. The acidic calcium sulfate, containing the radium, is discharged by means of slurry lines to a gypsum pile, from which part of the water is collected and recirculated. The wet-process phosphoric acid manufacture flowsheet, with typical radium concentrations at each stage, is shown in Figure 38. Eight wet-process phosphoric acid plants are in operation in Florida, with 19 additional plants scattered throughout the U. S.(12)

A 1973 study by the Environmental Protection Agency's National Field Investigations Center in Denver reports that water from recirculating gypsum slurry systems has between 60 and 100 pCi/l of radium-226. These concentrations exceed the Atomic Energy Commission standard for discharge to an unrestricted environment by two to three times. The AEC standard for release of radium-226 to an unrestricted environment is 30 pCi/l. Ground water collected in 1966 and 1973 in the Central Florida mining and processing area showed radium-226 concentrations in shallow aquifers as high as 76 pCi/l. The limit recommended by the U. S. Public Health Service for radium-226 in drinking water is three pCi/l.(112)

Reaction between the acidic waters carrying the waste gypsum and the limestone artesian aquifer underlying the ponds and gypsum piles has enlarged solution cavities in the aquifer

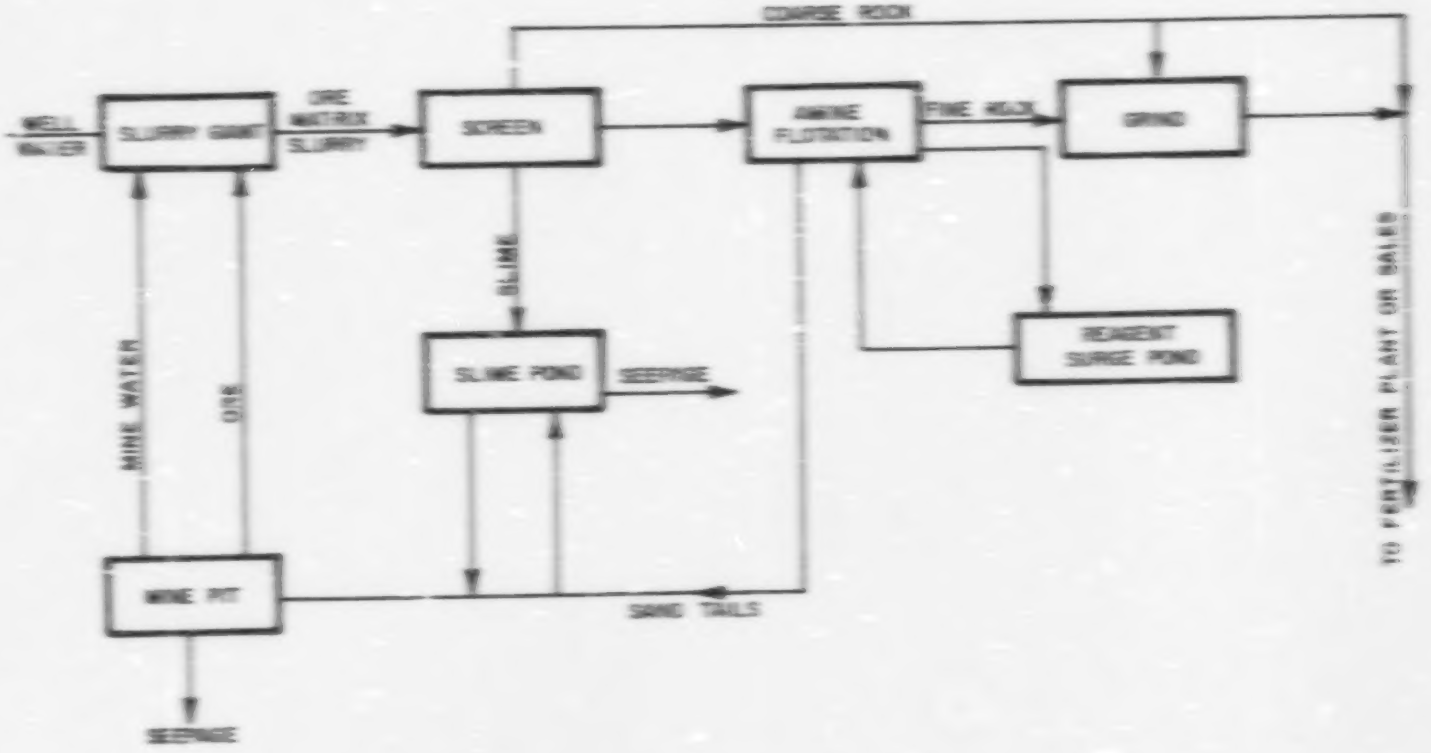

WELL WATER
SLURRY GIANT
ORE MATRIX SLURRY
SCREEN
COARSE ROCK
AMINE FLOTATION
FINE ROCK
GRIND
TO FERTILIZER PLANT OR SALES
SLIME
SLIME POND
SEEPAGE
REAGENT SURGE POND
MINE WATER
ORE
MINE PIT
SAND TAILS
SEEPAGE

Figure 37. Flowsheet, Florida phosphate rock mining and beneficiation.112)

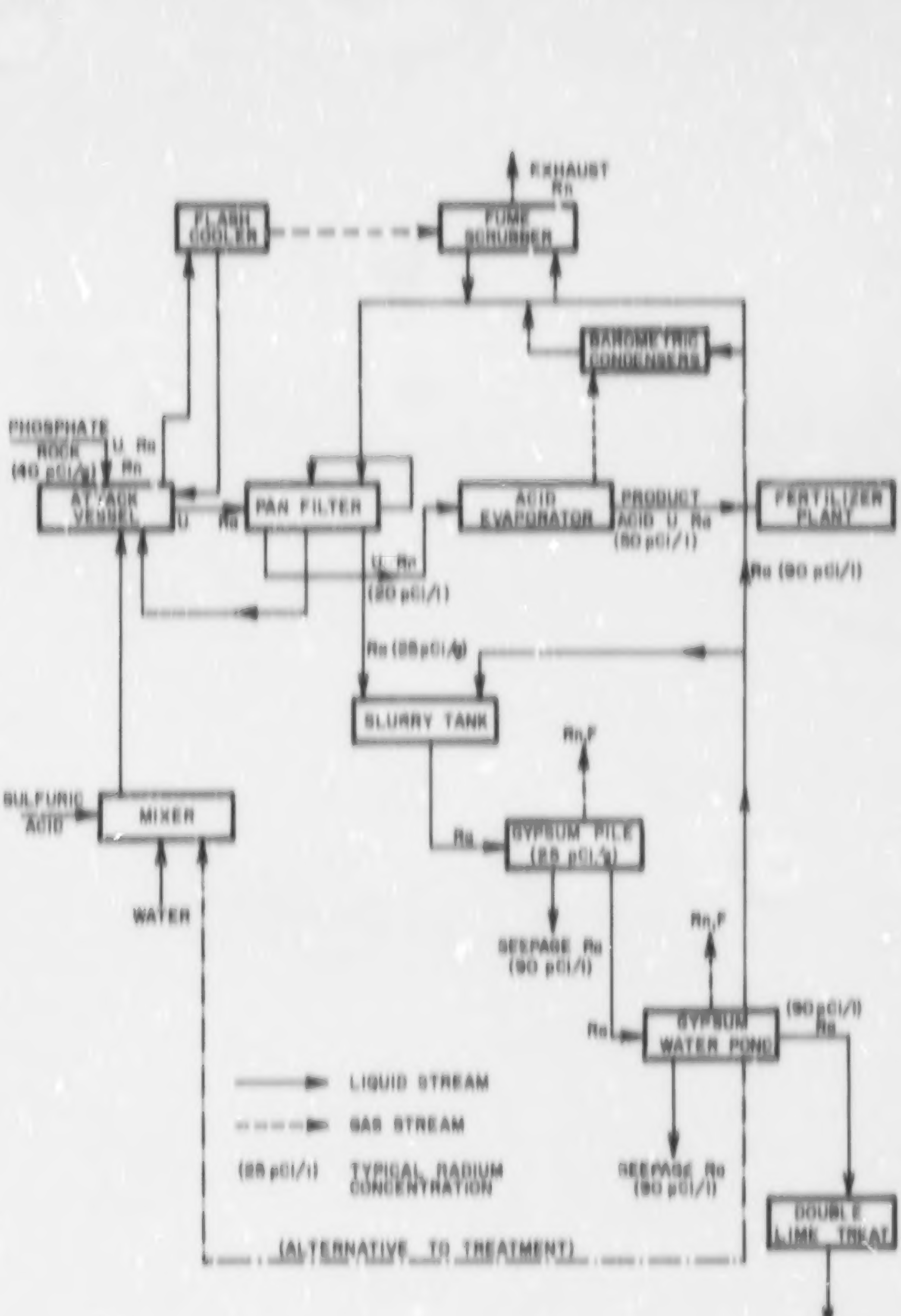

EXHAUST
Rn
FLASH COOLER
FUME SCRUBBER
BAROMETRIC CONDENSERS
PHOSPHATE ROCK
(40 pCi/g)
U Ra
Rn
ATTACK VESSEL
U Ra
PAN FILTER
ACID EVAPORATOR
PRODUCT ACID U Ra
(60 pCi/l)
FERTILIZER PLANT
U Ra
(20 pCi/l)
Ra (90 pCi/l)
Ra (25 pCi/g)
SLURRY TANK
Rn,F
SULFURIC ACID
MIXER
WATER
Ra
GYPSUM PILE
(25 pCi/g)
SEEPAGE Ra
(90 pCi/l)
Rn,F
Ra
GYPSUM WATER POND
(90 pCi/l)
Ra
LIQUID STREAM
GAS STREAM
(25 pCi/l)
TYPICAL RADIUM CONCENTRATION
SEEPAGE Ra
(90 pCi/l)
DOUBLE LIME TREAT
(ALTERNATIVE TO TREATMENT)
STREAM
(1 pCi/l)

Figure 38. Flowsheet, wet-process phosphoric acid manufacture.(12)

and permitted the movement of radioactive water into the shallow ground water over a large portion of Polk County, Florida. The region is part of the recharge area for the Floridan Aquifer which underlies the contaminated shallow aquifer. Some of the recharge to the Floridan occurs where sinkholes extend to the surface through the overlying confining units and the water-table aquifer. It is through these sinkholes or related solution cavities that radium-bearing water enters the aquifer.[113] Because of the large withdrawals of ground water from the Floridan Aquifer for mining and processing operations and for citrus irrigation, it is expected that contamination of the Floridan Aquifer will eventually take place. Many plants that report a negative water balance on the contaminated-water system are actually discharging radioactive waste waters to aquifers.[112]

There was little attempt in either of the studies referred to above to separate the ground-water samples on the basis of which were contaminated and which were not. However, in the 1966 report, if the inorganic chemical analyses are compared with the radium-226 concentrations of the water samples from the same wells, the wells can very distinctly be separated into two groups, as shown in Table 49. Additional chemical parameters are correlated with the radium-226 content and some very striking relationships are noted. The high NO_3 concentration can be attributed to oxidation of nitrogen compounds used in the amine flotation process, the low pH to seepage of acidic gypsum waters, and the low alkalinity to the low pH. The nitrate-alkalinity-pH-radium relationship is useful for determining if the waters are contaminated by fluids related to the beneficiation and the acidization processes.

Type 1 waters as reported in Table 49 can essentially be described as modified waters. However, the Type 2 waters may not all be the result of natural conditions. It is possible that some of these Type 2 water analyses which do list high concentrations of radium-226 reflect downward seepage of oxidized and leached materials from the original mined waste materials which were never acidized, but which were subject to the acidic action of natural rain. Rain in equilibrium with the atmosphere has a pH of 5.7.[120] From the data supplied, the mining stage cannot be said to be a contributing factor to contamination. However, past ore processing activities do seem to be a more likely source.

As a follow-up to the 1966 and 1973 EPA studies, the Florida State Radiological Laboratory and the U. S. Environmental Protection Agency sampled an additional 420 wells in 1975. Water samples were collected from wells in seven Florida

Table 49. COMPARISON OF CHEMICAL AND RADIONUCLIDES WATER SAMPLE ANALYSES FROM 26 WELLS IN THE CENTRAL FLORIDA PHOSPHATE MINING AND PROCESSING AREA.[113]

	Number of Samples	Nitrate[a] NO_3^-	pH	Alkalinity[a]	Radium-226[b]
Type of Waters[c]	3				
Range		7.4-26	4.1-5.1	0-4	4.5-76
Average		16.3	4.6	2.7	43.2
Type 2 Waters [c]	23				
Range		0-4	6.3-7.9	18-246	0.08-8.4
Average		0.4	7.4	119	1.76

a) mg/1
b) pCi/1
c) Water sample analyses segregated on the basis of chemical concentrations.

counties centered in and around the phosphate area. The results indicate that 68 percent of the wells contained waters with a radium-226 content exceeding the three-pCi/l U. S. Public Health Service drinking water standard.[114]

Case Histories

Acid mine drainage resulting from oxidation of sulfide minerals associated with coal has severely contaminated streams in the Cane Creek basin of Walker County, Alabama. The pH of the stream ranged from 2.9 to 5.2 during the period July, 1964 to June, 1965. The sulfate content of stream water at different points in the basin during January, 1965, ranged from 564 to 720 mg/l, and the pH ranged from 3.0 to 3.[illegible]. This high acidity has caused extensive damage to metals and concrete used in roadway culverts, and the water is not suitable for municipal or industrial use without extensive treatment.[121] Contaminants enter the streams by way of overland flow and ground-water discharge. The quality of the ground water in the area has not been investigated in detail, but it is conceivable that a large body of highly mineralized ground water exists under the mine area and is contributing to the base flow of the stream.

In a mining operation in York County, South Carolina, acid drainage resulting from oxidation of pyrite associated with the mineral kyanite has denuded approximately 200 acres, killing all vegetation and contaminating a nearby stream.[122] The extent of ground-water contamination has not been assessed and no water-supply wells are known to be located in the area.

Land subsidence, water accumulation at the surface, and saline-water problems have occurred in Saltville, Virginia, due to past salt-mining activities. Salt has been extracted by brine wells since the 1780's. Two sites were mined by injection of fresh water into wells penetrating the salt beds. A low-pressure brine well field removed about 7,846,000 cu m (277,050,000 cu ft) of salt from the site of the original seeps. High-pressure wells removed 7,919,000 cu m (279,620,000 cu ft) of salt from a mountain south of town. Land subsidence in the low-pressure well field was gradual and uniform, with 7 m (23 ft) of subsidence taking place between 1920 and 1953; there has been no subsidence in the interval 1963-1973. In the high-pressure well field where the caprock is a brittle dolomite, the subsidence was quite sudden. A cave-in on the mountainside took place in 1960, and deep fissures, rockfalls and subsidence occurred in the area of three brine wells.[123]

Naturally occurring salt springs existed in the area where ground water entering at a higher point passed through shale and salt beds and seeped out. Also, subsidence in the low-pressure brine well field mentioned above has resulted in a saucer-like depression which fills with water from rainfall, salt seeps, and leaking abandoned salt-mining wells. This water periodically floods portions of the town of Saltville. Total dissolved solids of approximately 11,000 mg/l are contained in waters pumped from the ponds at the rate of 530 l/s (8,400 gpm) every three days.123)

In late 1972 and early 1973, the low-pressure brine wells used by the chemical company mining the brine were plugged with concrete grout to a depth of 61 m (200 ft). At least 40 known wells were plugged, but some of these continued to flow at land surface. It is possible that well casings are corroded and that seepage is taking place at depth and entering the alluvium that overlies the shale and salt beds in the low-pressure area. A part of the salinity in the area can also be attributed to spills and leaks during the almost 200 years of salt extraction.123)

Phosphate mining by the dry, open-pit method was begun in 1965 at Lee Creek, Beaufort County, North Carolina. The mine was dewatered to a depth of 45.7 m (150 ft) by pumping approximately 227,000 cu m/d (60 mgd) of water from the artesian Castle Hayne aquifer which immediately underlies the phosphate ore body.124) As a result, the water levels in more than 900 domestic wells and 45 irrigation wells were lowered below suction limits. Figure 39 is an idealized geologic section through the Lee Creek Mine.125) The potentiometric surface has been lowered substantially at distances up to 64 km (40 mi) from the pumping site. During the period June, 1965, to January, 1968, it was lowered more than 1.5 m (5 ft) over about 3,367 sq km (1,300 sq mi), and fell below sea level in an area of more than 2,072 sq km (800 sq mi).126) Figures 40 and 41 show the potentiometric surface of the limestone member of the Castle Hayne aquifer just prior to pumping and two and one-half years later.

A rise in chloride concentration in the upper Castle Hayne aquifer unit from 30 mg/l in October, 1965, to more than 400 mg/l in July, 1972, was observed in monitor wells.127) The region has been declared a "Capacity Use Area" as of December 18, 1968, by the North Carolina Board of Water and Air Resources. Under the Water Use Act of 1967, the term is defined as one in which "the aggregate uses of ground water or surface water, or both, in or affecting said areas (1) have developed or threatened to develop to a degree

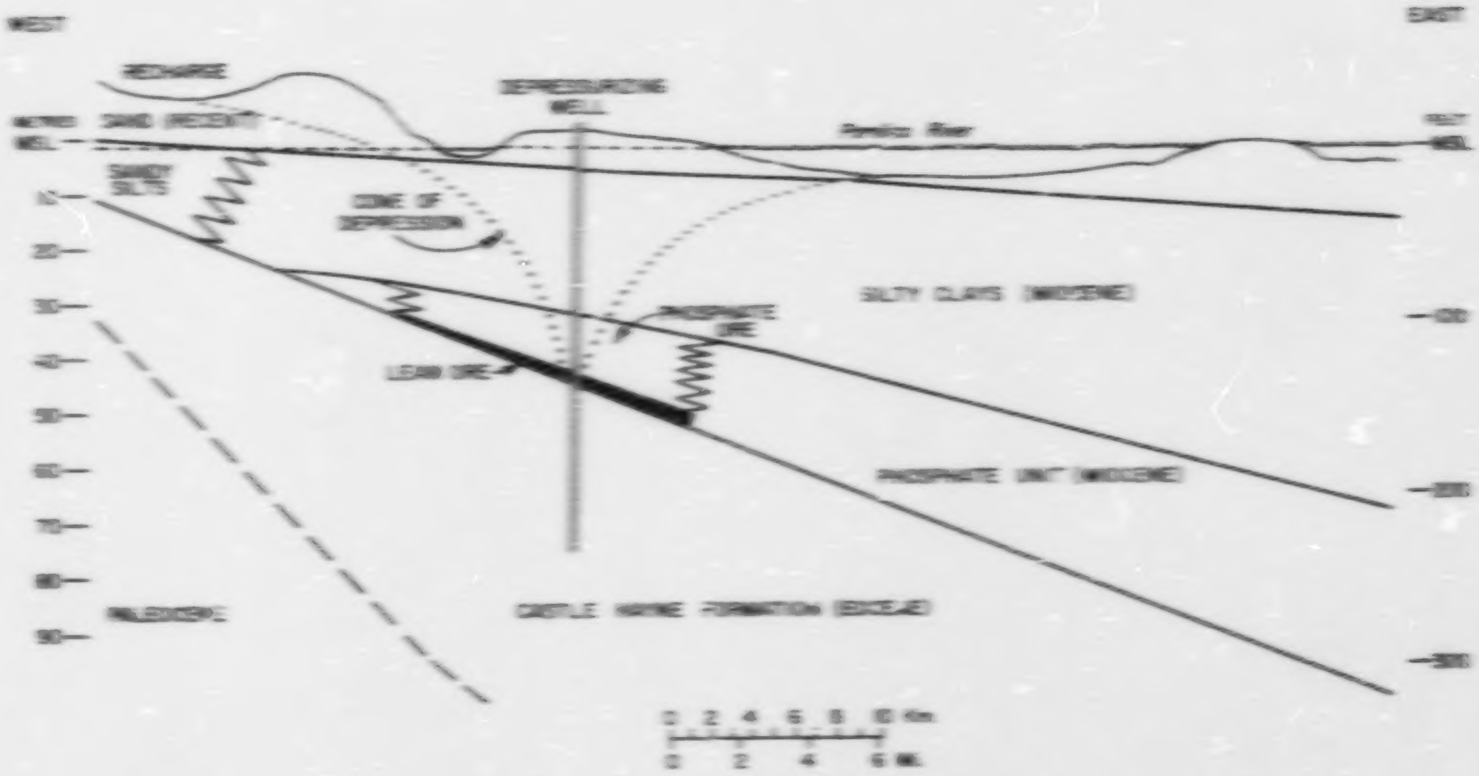

WEST
EAST
RECHARGE
DEPRESSURING WELL
METERS
SAND (RECENT)
MSL
Pamlico River
FEET
MSL
SANDY SILTS
CONE OF DEPRESSION
SILTY CLAYS (MIOCENE)
PHOSPHATE ORE
LEAN ORE
PHOSPHATE UNIT (MIOCENE)
CASTLE HAYNE FORMATION (EOCENE)
PALEOZOIC
10
20
30
40
50
60
70
80
90
-100
-200
-300
0 2 4 6 8 10 Km
0 2 4 6 MI.

Figure 39. Idealized geologic section thru the Lee Creek mine, Beaufort County, North Carolina.125)

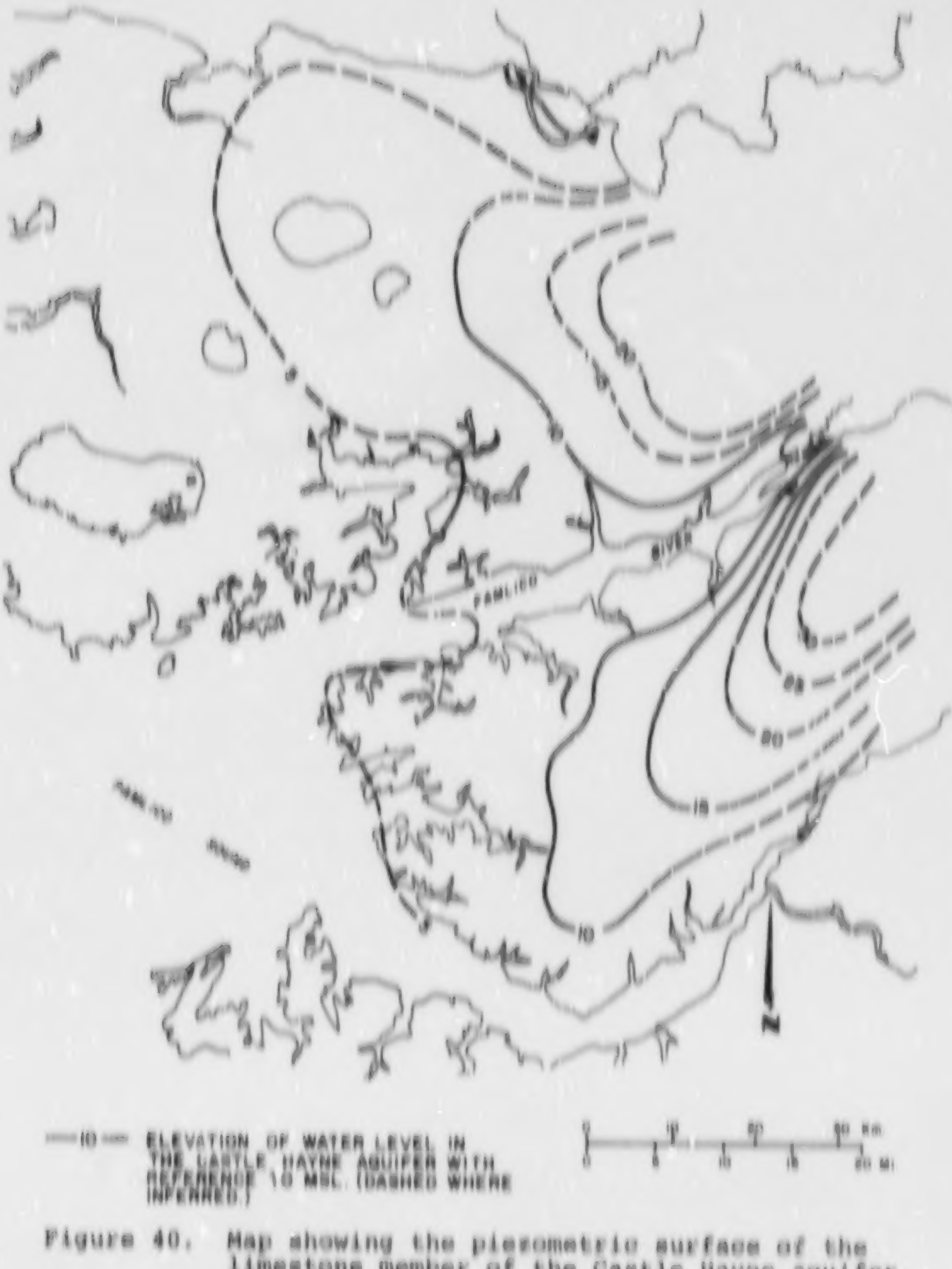

PAMLICO
RIVER
10
15
20
25
30
N
—10— ELEVATION OF WATER LEVEL IN THE CASTLE HAYNE AQUIFER WITH REFERENCE TO MSL (DASHED WHERE INFERRED)
0 10 20 30 KM
0 5 10 15 20 MI

Figure 40. Map showing the piezometric surface of the limestone member of the Castle Hayne aquifer, June 1565,126)

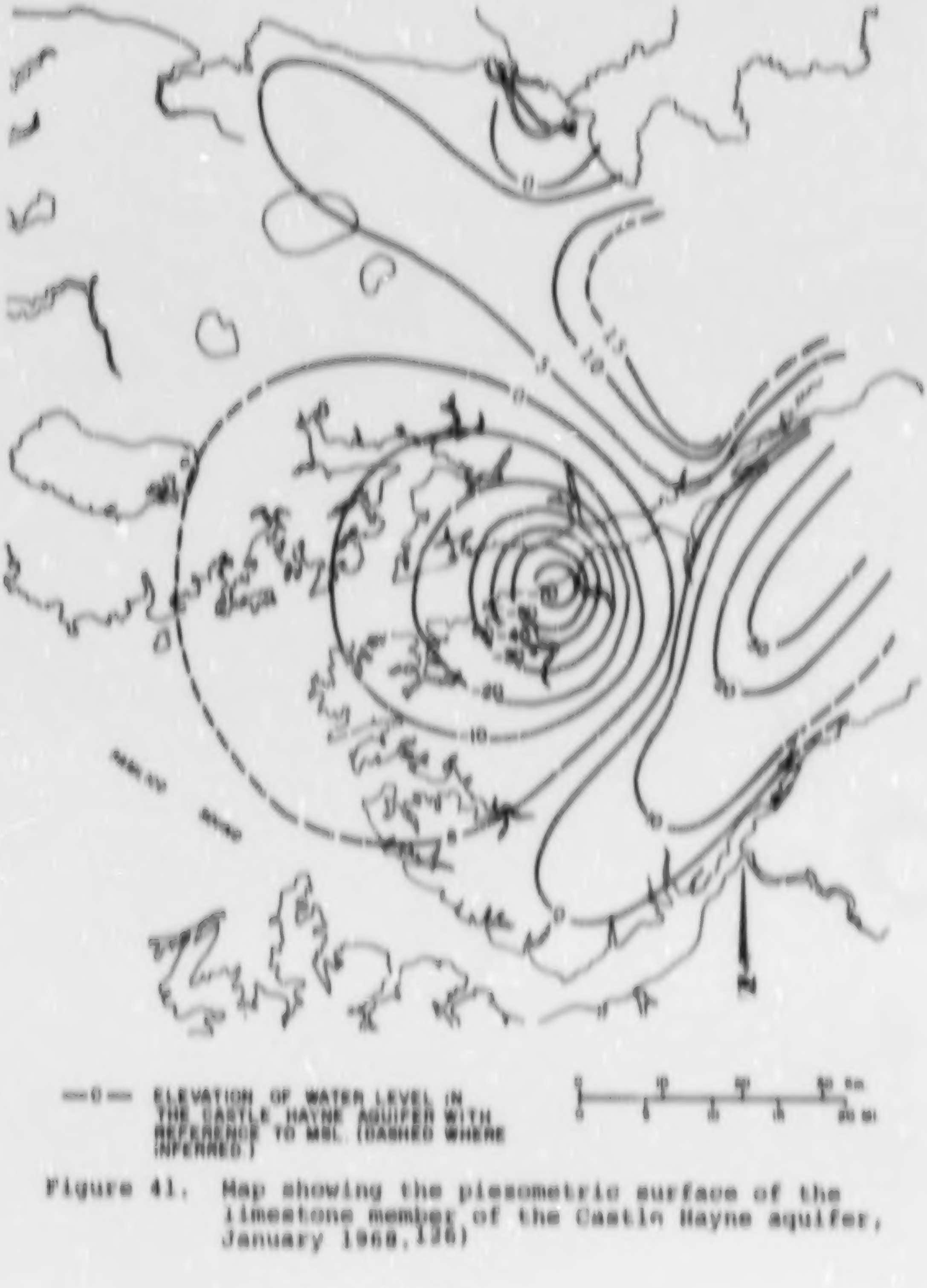

0
5
10
15
0
-10
-20
-30
0
0
0
0
—0— ELEVATION OF WATER LEVEL IN THE CASTLE HAYNE AQUIFER WITH REFERENCE TO MSL (DASHED WHERE INFERRED)
0 10 20 30 km
0 5 10 15 20 mi
N

Figure 41. Map showing the piezometric surface of the limestone member of the Castle Hayne aquifer, January 1968.126)

which requires coordination and regulation, or (2) exceeds or threatens to exceed, or otherwise threatens or impairs, the renewal or replenishment of such waters or any part of them."[127]

In early 1975, a sinkhole opened up under a waste gypsum stockpile near Mulberry, in Polk County, Florida. During a three-week period, 17 million l (4.5 million gal) of gypsum leachings (with a radium-226 value of ± 91 pCi/l) and 68,800 cu m (90,000 cu yd) of solid gypsum (23 pCi/g) entered the ground water through the sinkhole. Although the pH of the liquid effluent was less than 2.0, piezometers around the stockpile yielded water above pH 7.0. This phenomenon and the sudden collapse were explained by the discovery that the site was highly fractured and subject to sinkhole formation. Inspection of aerial photographs taken prior to use of the site for waste gypsum stockpiling revealed that the area is cut by many long lineations representing fractures extending to land surface. The collapse took place at the intersection of two of these lineations. Prior to collapse, the acidic leachings from the stockpile enlarged the fractures, permitting more rapid downward movement of contaminant fluids and eventually structural weakening of the area. There was essentially no lateral movement of the radioactive, acidic solutions.[128]

Future Trends

Mining will continue to increase in the Southeast, responding to the demands of a production-oriented society. The areas of the Southeast most likely to feel the impact of such contamination are those which contain deposits of minerals and mineral fuels that are going to be needed in increasing quantities in the coming years. The principal materials that will continue to be mined in future years will be phosphate rock in North Carolina and Florida, bituminous coal in Alabama and Virginia, and iron in Alabama. The principal minerals produced in the Southeast and the national rankings are given in Table 50.

With the increasing demand for coal, phosphate, and other minerals, it can be expected that economically marginal deposits or abandoned deposits will be mined. Additionally, there will be an expansion in the reworking of tailings piles as the methods of mineral beneficiation become more effective and the prices of minerals increase. This may have two effects: 1) the incidence of ground-water contamination will increase if old practices causing such contamination are not modified in the new mining areas, and

Table 50. PRINCIPAL MINERALS PRODUCED IN THE SOUTHEAST STATES.125)

Minerals	Principal Producing States and National Ranking
Aplite	Virginia (1)
Asbestos	North Carolina (4)
Asphalt (Native)	Alabama (3)
Barite	Georgia (4)
Bauxite	Alabama (2), Georgia (3)
Clays	Georgia (1), North Carolina (4)
Feldspar	North Carolina (4)
Kyanite	Virginia (1), Georgia (2), Florida (3)
Lithium Minerals	North Carolina (1)
Mica, scrap	North Carolina (1), Alabama (2), Georgia (3), South Carolina (4)
Mica, sheet	North Carolina (1)
Olivine	North Carolina (2)
Phosphate Rock	Florida (1), North Carolina (4)
Rare Earth Metal Concentrates	Georgia (2)
Staurolite	Florida (1)
Titanium Concentrate	Florida (2), Georgia (4)
Tungsten Concentrate	North Carolina (3)
Vermiculite	South Carolina (2)
Zircon Concentrate	Florida (1), Georgia (2)

2) contamination will decrease if old tailings piles are reworked for additional mineral content, followed by proper land reclamation practices.

Although present land reclamation practices have as their primary purpose the reduction or prevention of acid mine drainage to streams, other methods that decrease the contact between water and acid-producing materials also will help to lessen the impact on ground water. Mines, whether surface or underground, cover large areas and will always produce contaminants. The most practical control method is removal of as much water from the surface as possible, either through drainage systems and grading techniques or through evapotranspiration of moisture by proper vegetation. Waste materials should be disposed of in such a manner that oxidation processes are inhibited and contact with water is minimized. Acids seeping from mines should be neutralized so that they do not re-enter the ground-water system to cause further solution of minerals and contamination of aquifers.

SEPTIC TANKS

Ground-water contamination as a result of the use of septic-tank systems has occurred in all seven states in the report area. This method of domestic waste disposal is used in rural areas or in suburbs beyond municipal or county sewer district service areas. The major growth in septic-tank use took place after World War II due to the rapid development of suburban areas around major cities. Prior to that time septic tanks were used primarily in rural areas.

Approximately 4,339,000 individual housing units, representing 45 percent of the population in the southeast study area, dispose of their domestic wastes through individual on-site disposal units.(6,110) These are primarily septic tanks and cesspools, although in some of the states there are almost as many privies as other types of on-site units. Table 51 lists the number of on-site disposal systems in the Southeast, by state.

Figure 42 shows three ranges of density of housing units using on-site domestic waste disposal units in the Southeast: less than 3.8/sq km (10/sq mi); between 3.8 and 15.4/sq km (10 and 40/sq mi); and more than 15.4/sq km (40/sq mi). Data for Figure 42 were obtained from the "1970 Census of Housing" and mapped on a county-by-county basis. It should be noted that, even in counties having a low density, large concentrations of disposal units may exist in urbanized areas. Table 52 lists those counties in the

Table 51. NUMBER OF ON-SITE DISPOSAL SYSTEMS IN THE SOUTHEAST, BY STATE.(1)

State	Number of On-Site Disposal Systems
Alabama	584,524
Florida	981,097
Georgia	615,121
Mississippi	357,497
North Carolina	882,932
South Carolina	441,211
Virginia	512,589
Total	4,338,971

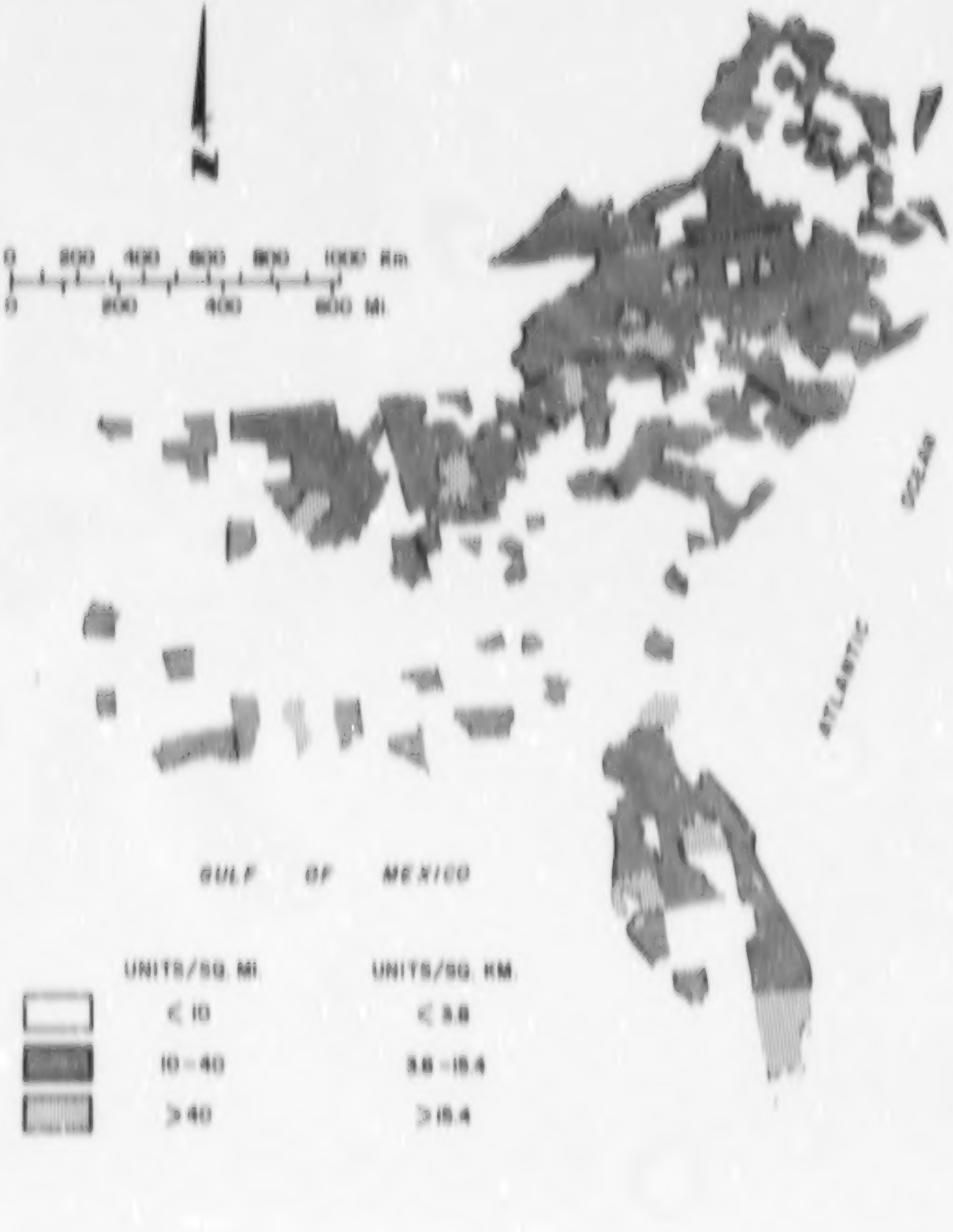

N
0 200 400 600 800 1000 Km
0 200 400 600 MI.
GULF OF MEXICO
ATLANTIC OCEAN
UNITS/SQ. MI.
UNITS/SQ. KM.
< 10
< 3.8
10 - 40
3.8 - 15.4
> 40
> 15.4

Figure 44. Density of housing units using on-site domestic waste disposal systems.

Table 52. COUNTIES IN THE SOUTHEAST UNITED STATES WITH MORE THAN 50,000 HOUSING UNITS USING ON-SITE DOMESTIC WASTE DISPOSAL SYSTEMS.6)

Jefferson, Alabama

Duval, Florida

Dade, Florida

Broward, Florida

Hillsborough, Florida

Southeast with a total of more than 50,000 housing units using on-site waste disposal systems.

The volume of waste fluid handled by disposal systems can be large. For example, it is estimated that in 1970, nearly 175,000 septic tanks in Dade County, Florida, were discharging about 151,400 cu m/d (40 mgd) of domestic waste water into the highly permeable Biscayne aquifer, the primary source of fresh water in the county.(31)

The complete septic-tank and tile-field system consists of three basic components. The first is the septic tank itself, which is a watertight, non-corrosive, covered receptacle designed to remove solids by settlement and to trap and store scum and sludge. The second is the distribution box which distributes effluent to the several lateral lines of the tile field. The third component is the soil absorption system or tile field. This consists of a series of pipes, usually made of perforated fiber or plastic material, the purpose of which is to distribute the sewage effluent as evenly as possible over an area of soil large enough to absorb it. The distribution lines are normally laid in trenches, backfilled with filter material consisting of washed gravel, crushed stone, or slag. Figure 43 shows the layout of a typical septic tank-soil absorption system.

The acceptability of a site for a septic-tank system is commonly based upon the ability of the local soil to absorb water at a fast enough rate to handle the anticipated volume of effluent. A percolation test is used to determine the suitability of the soil for such use. The slower the percolation rate, the larger the tile absorption field must be. It is assumed that if the percolation (absorption) rate is acceptable and the tile field is large enough, there will be removal of organic materials from the effluent by natural adsorption and biological processes in the soil zone in the immediate area of the tile field. However, it must be pointed out that high absorptive capacity as determined by the percolation test does not necessarily correlate with the adsorptive capacity of the soil. For this reason, many soils of high absorptive capacity can be overloaded with organics as a result of low adsorption.

It is generally accepted that as much as 300 mg/l of total dissolved solids are added to water by domestic use; thus, the effluent from septic tanks can increase the concentration of minerals in ground water. Table 53 shows the range of mineral pickup in domestic sewage. Under normal conditions of soil pH, efficient removal of phosphates can take place; however, chlorides, nitrates, sulfates, and

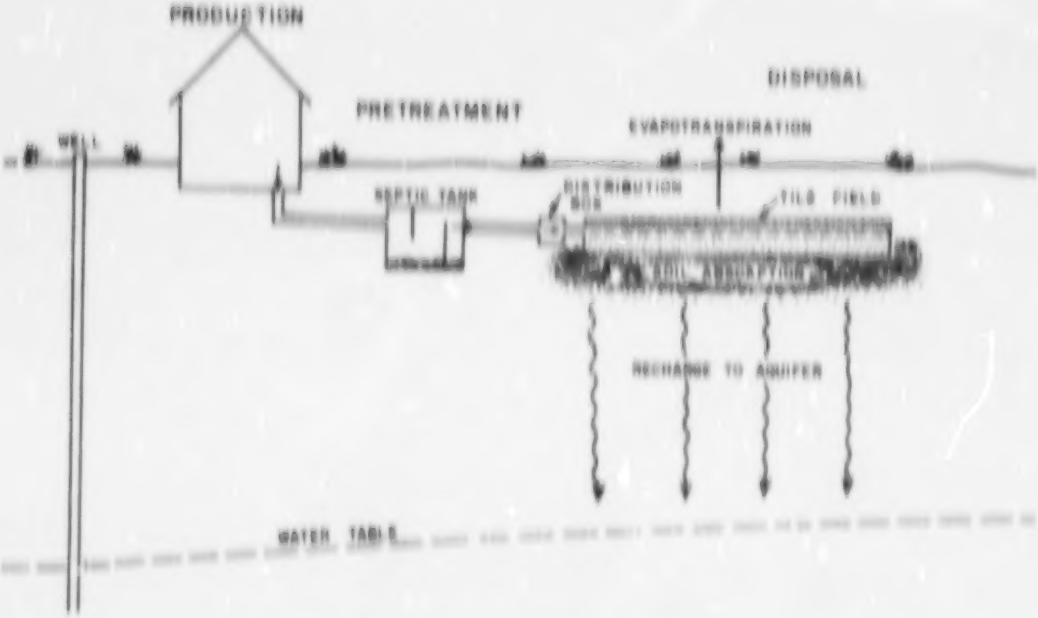

PRODUCTION
WELL
PRETREATMENT
DISPOSAL
EVAPOTRANSPIRATION
SEPTIC TANK
DISTRIBUTION BOX
TILE FIELD
SOIL ABSORPTION
RECHARGE TO AQUIFER
WATER TABLE

Figure 43. Disposal of household wastes through a conventional septic tank-soil absorption system.132)

Table 53. NORMAL RANGE OF MINERAL PICKUP IN DOMESTIC SEWAGE.113)

Mineral	Mineral range (mg/l)
Dissolved solids	100 - 300
Boron (B)	0.1 - 0.4
Sodium (Na)	40 - 70
Potassium (K)	7 - 15
Magnesium (Mg)	3 - 6
Caldium (Ca)	6 - 16
Total Nitrogen (N)	20 - 40
Phosphate (PO_4)	20 - 40
Sulfate (SO_4)	15 - 30
Chloride (Cl)	20 - 50
Alkalinity (as $CaCO_3$)	100 - 150

bicarbonates can often enter a ground-water body and move freely. Bacteria and viruses are normally removed by the soil system but, under conditions favorable for their survival, can reach the water table and can travel significant distances through an aquifer. Some other pollutants that have been found associated with septic tanks include synthetic detergents, excessive chlorides from water softener regeneration, and, in special cases where industrial wastes have been discharged to a septic tank, a number of toxic and non-toxic constituents.

Figure 44 is a schematic diagram of the reactions that occur when nitrogen is added to the soil. Oxidizable nitrogen compounds entering the soil in septic tank effluent are converted to nitrite by the soil bacteria *Nitrosomas spp.* and from nitrite to nitrate by *Nitrobacter spp.* In order for these conversions to take place the soils must have favorable moisture, temperature, and oxygen content (all such conditions are generally met in well-drained soils). Nitrification will not take place if the soil is so waterlogged that reducing conditions result. Overloading the soil with oxidizable organics will also inhibit nitrification.(134)

In areas with well-drained soils and a low water table, most agencies responsible for septic-tank approvals find that percolation tests indicate the sites to be acceptable. From a purely physical and, generally, biological viewpoint they are acceptable. Fluids from the septic tank tile field would percolate downward, pathogenic organisms would be filtered out, and there would be no surface overflow or seepage. However, the ground-water would become contaminated in varying degrees by nitrates generated from the organic nitrogen compounds in the downward-percolating effluent.

In areas that are generally rejected for septic tank installation because of high water tables and impermeable, waterlogged soils, septic tank effluent moves either toward the land surface at the site or laterally toward low points or bodies of water in an essentially aseptic condition. In this manner, direct bacterial contamination of shallow or poorly-constructed wells can occur during periods of rainfall and overland runoff.

Septic-tank effluent can easily contaminate ground water when fractured crystalline rock lies close to the land surface. Fluids leaving tile fields have little opportunity to be filtered by the thin soil horizon and enter the ground-water environment by means of the fractures in the rock. Movement of water along these fractures is quite

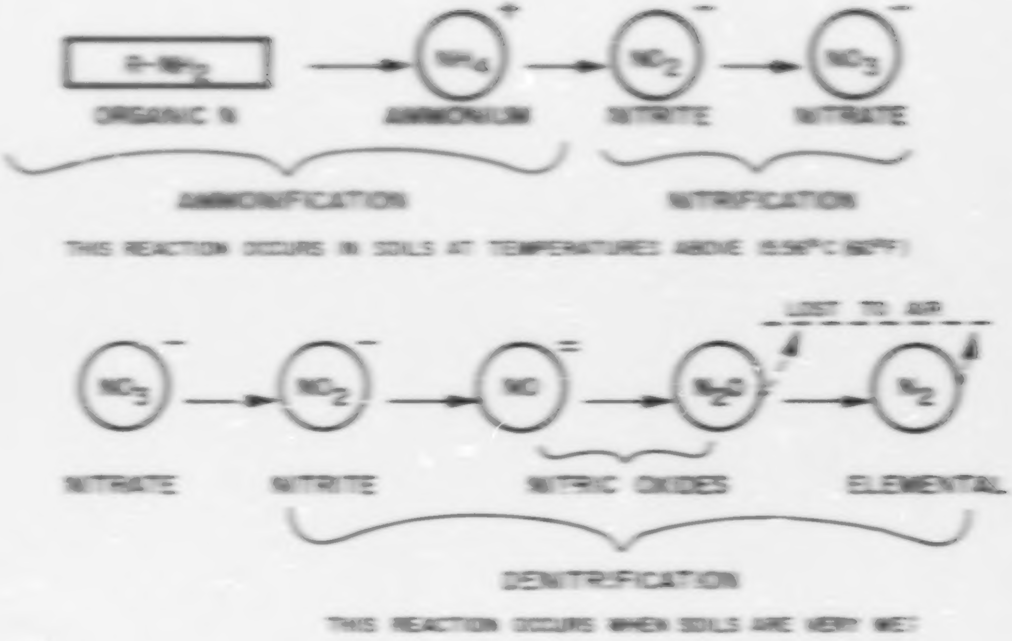

R-NH2
ORGANIC N
NH4+
AMMONIUM
NO2−
NITRITE
NO3−
NITRATE
AMMONIFICATION
NITRIFICATION
THIS REACTION OCCURS IN SOILS AT TEMPERATURES ABOVE 15.56°C (60°F)
LOST TO AIR
NO3−
NITRATE
NO2−
NITRITE
NO
N2O
NITRIC OXIDES
N2
ELEMENTAL
DENITRIFICATION
THIS REACTION OCCURS WHEN SOILS ARE VERY WET

Figure 44. Soil reactions that occur when nitrogen is added to soil.[134]

rapid compared to movement in a sand aquifer. Wells tapping the fractured rock are thus susceptible to both chemical and biological contamination.

The above suggests that the percolation tests commonly used to evaluate a site for septic-tank use are valid if one is concerned only with physical disposal of the effluent. However, those sites shown on soils maps or septic-tank suitability maps as being acceptable are in many cases unacceptable from a chemical viewpoint because ground-water contamination results.135,136,137,138)

In a more detailed look at the problem of actual septic-tank failure, not just surface overflow or tile-field clogging, Bouma reports on some very realistic methods of resolving failures under each of various pedologic and hydrogeologic conditions. Subsurface denitrification systems are being planned for use with absorption mounds over shallow soils on creviced bedrock and with seepage beds in highly-drained sands. Seepage beds in moderately permeable loams and silt loams tend to crust and clog resulting in surface discharge of contaminated raw effluent; through use of the dual bed system these can be revived by alternating use. Soils of low permeability are made more usable with the creation of larger subsurface seepage beds and with soil-mounding techniques that provide a greater receptive surface area to the effluent.139)

Two techniques are used for effluent disposal in areas subject to ponding of rainwater in silty subsoil layers of low permeability and in areas with shallow water-table conditions. The first necessitates removal of the low permeability material and placement of seepage beds in more permeable material that might underlie the area, and the second calls for use of a mound system.140)

One approach that might be considered with regard to site evaluation before any septic-tank systems are placed in a developing area would be to determine the oxidation-reduction potential (ORP) of the ground water, assuming that water-table conditions exist. In general, areas of high nitrate contain oxidizing waters and areas of low nitrate contain reducing waters. If there is free vertical movement of percolating rain water, even if it is slow, it is likely that a determination of the ORP of the waters will be useful in assessing possible chemical reaction. Predictions can be made as to whether nitrification (NO_2 and NO_3 formation), denitrification (elemental nitrogen formation), or ammonification (ammonium formation) will take place.

Various areas of Florida contain waters where ammonification processes are taking place. Muck soils in Conservation Area 3 and the interior undeveloped marshlands of Dade County produce high organic nitrogen and ammonia values in water. Due to the lack of oxygen, the microbial oxidation of nitrogen in ammonia to nitrite and nitrate does not occur. Percolating rainfall carrying dissolved oxygen favors bacterial nitrification. In the northern part of Dade County, where the Biscayne aquifer has a low permeability and consists of sand and limestone, reducing conditions exist and the nitrate content is low; to the south, where the aquifer is a highly permeable limestone, the water is oxidized and has a high nitrate content.(31)

During the course of preparing this report, it became apparent that the occurrence of nitrate in concentrations approaching or exceeding the U. S. Public Health Service limit of 45 mg/l (as NO_3) corresponded geographically and geologically with the outcrop areas of aquifers, particularly the sands and sandstones. Downdip in these same aquifers the nitrate concentration was much less. In these outcrop areas, high-density developments (houses on 1/4- to 1/2-acre lots) which utilize septic-tank systems will tend to cause formation of high-nitrate ground water, which may then enter shallow domestic wells.

Case Histories

Pollution of a large spring in Gordon County, Georgia, was discovered when the City of Calhoun tried to use the spring to supplement its water supply. Total coliform density of three water samples taken over a 30-day period in 1971 ranged from 240 to 2,300 per 100 ml. The fecal coliform density ranged from 15 to 430 per 100 ml. The source of the bacteria was a septic tank nearly half a mile away. The construction practice of removing too much soil when installing the septic tank above fractured bedrock was the presumed cause of the rapid movement of the septic tank effluent.(40)

In Bartow County, Georgia, just south of the foregoing area and in the same kind of fractured and cavernous rock, a study showed that of 194 private water supplies sampled, 50.5 percent were polluted.(41) The general practice of locating water-supply wells for convenience and economy rather than for safety of the supply is a major contributing factor to this condition.

An epidemic was reported at a Girl Scout camp in northern Floyd County, Georgia, when a spring utilized as the source of water became contaminated. Tests revealed that bacteria reaching the spring originated in recently installed flush toilets at the camp. Fluorescein dye flushed down the toilets appeared in the spring water in less than 48 hours. The dye passed through the septic tank, seeped from the field lines into the aquifer, and traveled several hundred feet along the bedding planes of the rock to the spring.142)

In Chesterfield County, South Carolina, 45.6 percent of 217 rural water supplies contained arsenic exceeding the U. S. Public Health Service limit (0.05 mg/l); arsenic was detected in 91 percent of the samples. There is a significant statistical correlation between nitrate, phosphate, chloride and arsenic concentration and the distance of the water-supply source from the septic tank; the concentrations decrease with increased distance. The source of the arsenic is synthetic detergents passing through the septic-tank system and into the ground water.143)

In Anson County, North Carolina, water samples from seven wells 12 to 47 m (39 to 155 ft) deep contained abnormally high concentrations of nitrate, which ranged from 18 to 94 mg/l.144) This is considerably above the natural background level of one mg/l (median of 467 well samples) found in the fractured rocks in the North Carolina Piedmont (see Natural Ground Water Quality Section of this report). All of the wells are located in rural areas, and septic tanks and barnyards are suspected to be the sources of the contaminant.

Four counties in Georgia, each located in a different hydrogeologic setting, were selected for a survey of ground-water quality. The counties were Wayne County in the Atlantic Coastal Plain; Mitchell County, in the Dougherty Plain of the Gulf Coastal Plain, which has a shallow limestone aquifer in which sinkholes are prevalent; Coweta County, in the Piedmont Province, where fractured metamorphic rocks occur; and Bartow County in the Valley and Ridge Province, where fractured and cavernous carbonate rocks are common.96)

The well construction methods fell into five categories: dug, driven, jetted, bored, or drilled. Table 54 lists sources of rural water supply by type that exceed the nitrate standard in each county. A total of 43 out of 760 samples in all counties exceeded the U. S. Public Health Service standard for nitrate. Shallow dug wells had the highest incidence of nitrate contamination (28 of the 43 wells sampled); a similar incidence of high coliform was noted. In general, the larger the number of dug wells in use, the greater was the percentage of contamination. Coweta County, with the greatest number of dug wells, had the highest percentage of contaminated wells; verified

Table 54. COMPARISON OF TYPE OF WATER-SUPPLY WELLS EXCEEDING NITRATE CONCENTRATION STANDARD IN GEORGIA.[96]

	Types of Wells					
County	Dug	Driven	Jetted	Bored	Drilled	Total
Bartow	5	0	0	0	2	7
Coweta	13	0	0	3	0	16
Mitchell	5	0	0	0	3	8
Wayne	5	5	1	1	0	12
TOTAL	28	5	1	4	5	43

coliform and fecal coliform counts were 59.5 percent and 24 percent, respectively. Bartow County was second with 49.7 percent and 19 percent, Mitchell County was third with 26.0 percent and 9.5 percent, and Wayne County was lowest with 18.9 percent and 6.1 percent.96)

A survey of 62 wells in 12 housing subdivisions where septic tanks were in use was undertaken in Raleigh, North Carolina. The report concluded that, although no appreciable amount of detergent buildup had occurred, zones of high nitrate and chloride were forming. Most of the homes were on lots ranging in size from a quarter acre to more than a half acre, and most of the wells were drilled into fractured granites, schists and gneisses to depths of 30.5 to 61 m (100 to 200 ft). Septic tanks were generally located at the lower part of each lot, whereas the wells tended to be at slightly higher elevations.145)

Nitrates in amounts of more than nine mg/l do not occur naturally in the Raleigh area, and chlorides of more than ten mg/l are uncommon. Water from 10 of the 62 wells sampled in 1962 had a high nitrate concentration or a combined high chloride and high nitrate concentration. The range in nitrate concentration was 0.0 to 24 mg/l with an average of 4.3 mg/l. The range in chloride concentration was 0.2 to 67 mg/l with an average of 5.5 mg/l.145) Although the nitrate concentrations do not exceed the U. S. Public Health Service standard of 45 mg/l, the indication of nitrate buildup due to septic tank contamination was confirmed. A similar trend has been observed in other areas of the U. S., especially in the major suburbanized areas of the northeastern states where excessive nitrate levels are found in some of the water supplies.146) The implications are that the Raleigh area is in a transitional stage which has not yet reached the recommended limit for nitrate concentrations.

A similar pattern of increasing nitrate concentration seems to be taking place in the sanc and gravel aquifer of Pensacola, Florida. Nitrate levels as high as 44 mg/l have been recorded in isolated areas, but in the downtown area of the city, there is a definite trend toward increasing nitrate. The highest concentration was 17 mg/l in 1970; only two years before it had been 8.3 mg/l. This same trend of increases ranging from 10 to 88 percent has been noted in other wells sampled during the two years. Possible sources of contamination are septic tanks, industries, and sewer lines.147)

Scattered wells in the Athens, Alabama, area are producing water with high concentrations of nitrate. South of the town a spring and two wells contained 40 to 50 mg/l of nitrate. The source of the contamination appears to be septic tanks and a sewage lagoon used by a nearby school.[148] To the north at sites west of Elkmont, Alabama, three wells constructed in the Chickamauga Limestone have nitrate levels of 57, 97, and 111 mg/l and chloride levels of 56, 43, and 13 mg/l, both indicative of contamination by septic tank effluent.[149]

A well in the Fayetteville, North Carolina, area had a nitrate concentration of 258 mg/l. The fluids from a septic tank drainfield located 46 m (150 ft) from the 51 cm (20 in) diameter shallow bored well moved along large, decaying tree roots which channeled the seepage to the well. The well was abandoned and replaced with a 117 m (385 ft) deep well cased to 57 m (187 ft).[150]

In 1970, the public water supply of a residential community in Mecklenburg County, North Carolina, was polluted by septic tank effluent. The well had been properly constructed and surface drainage had been ruled out as the cause. For the 1,000 people utilizing the well, 505 cases of shigellosis were reported.[54] A similar incident of 44 cases of gastroenteritis (shigellosis) was reported at a YMCA camp near Waco, Georgia, in 1968. The contamination was attributed to septic tank effluent.[54]

Two wells, one within 15 m (50 ft) of a septic tank and another inducing flow from a stream fed by a contaminated lake, are considered to be responsible for 64 cases of gastroenteritis in 1967 in Fauquier County, Virginia. A total of 83 people were exposed to water from the contaminated wells.[54]

A detailed study of selected areas serviced by septic tanks in Dade County, Florida, showed that inland areas, remote from urban development, have ground water naturally high in organic nitrogen, ammonia, organic carbon, and chemical oxygen demand. The presence of septic tank effluent in developed areas was consistently indicated by high ammonia, nitrogen, phosphorus, fecal coliform bacteria, and sodium. Uniformly high nitrate values in the Homestead, Florida, area are attributed to agricultural activity; lawn fertilizers may be contributing a portion of the nitrates in other areas. The radical differences in nitrogen chemistry of water from the different sites in the county were related to: 1) nature of soil cover; 2) proportion of sand to limestone in the subsurface; 3) internal drainage of the sediments; 4) proximity to agriculture; and 5) presence of septic tank effluent.[151]

Future Trends

In spite of their potential for causing ground-water contamination, millions of septic tanks will continue to be used in the region, and their overall numbers may increase over at least the next decade. The reasons for this include:

1. The lack of other acceptable alternatives for domestic waste disposal in unsewered areas;

2. Existing limitations on local, state, and Federal budgets which prevent installation of public sewers to meet waste disposal needs of expanding suburban communities;

3. New environmental criteria calling for the upgrading of community sewage treatment plants. This slows down the expansion of these central systems into unsewered areas;

4. The continued resistance by residents in many parts of the study region to approve the large expenditures necessary for conversion from on-site disposal systems to sewered communities;

5. The long time period required for a public system to become fully operational, even in areas where the density of housing and problems of ground-water contamination justify the need for conversion to collecting sewers and treatment plants.

Probably the best approach to limiting future problems is better governmental control and planning. Zoning and land-use planning in areas where septic tanks will be required should be based on a thorough understanding of regional variations in topography, soils, aquifer characteristics, and recharge and discharge relationships involving ground water and surface water. An initial study in a particular region leading to recommendations on planning procedures and guidelines for on-site waste disposal facilities would be the most environmentally sound approach; errors that might be even more costly and controversial over the long term might then be prevented. Research is needed to develop the tools that can be used for decision-making related to septic-tank feasibility and density. In this way, ground-water quality can be better protected.

LAND DISPOSAL OF WASTE WATER

There has been increased interest in land disposal of municipal and industrial waste water as a result of the 1972 Amendments to the Federal Water Pollution Control Act, which established goals of higher water quality. The major problem associated with this method of disposal is that it cannot be considered a standard solution to be applied anywhere but must be evaluated on a site-by-site basis; physical, chemical, and biological properties of the site and the waste water itself must be taken into account.

Usage of land for disposal of waste water was taking place prior to the turn of the century, and a 1935 survey listed 113 localities in 15 states practicing irrigation of crops with waste water.[151] Another survey, in 1972, notes 316 localities in 13 states practicing such crop irrigation; most of the locations noted in the 1935 survey reappeared in the 1972 survey.[152] The increase in the number of systems applying waste water to the land is shown in Table 55.

Three methods of applying waste water to land areas are in use: spray irrigation, overland flow, and rapid infiltration (Figure 45). Spray irrigation is the controlled spraying of waste effluent on moderately permeable soils at a rate measured in centimetres per week to support plant growth; the flow paths of the water are infiltration and percolation within the area of the disposal site.[154,155] In this process, pollutants in the effluent are either taken up by plants, converted to neutral substances in the soil, or adsorbed onto the soil particles.

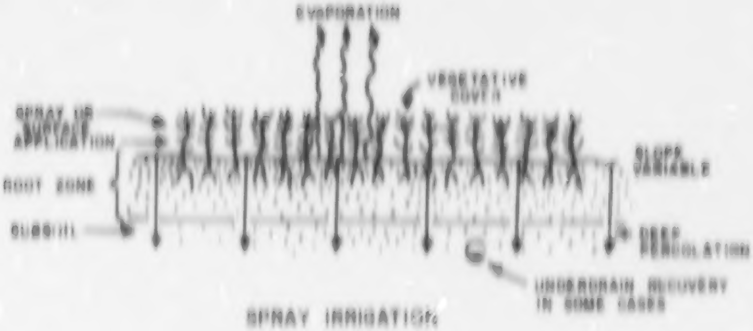
Overland flow is the controlled discharge of effluent by spraying or other means onto relatively impermeable soils at a rate measured in centimetres per week; the flow path of the water is downslope sheet flow.[154,155] Vegetative cover is used to reduce erosion and to provide a suitable habitat for microorganisms participating in the purification process.

Rapid infiltration is the controlled discharge of effluent by spreading or other means onto very permeable soils at a rate measured in tens of centimetres per week; the flow paths of the water are high-rate infiltration and percolation.[154,155] Pollutants in the effluent are removed by physical, chemical, and biological processes as they travel through the soil and subsoil.

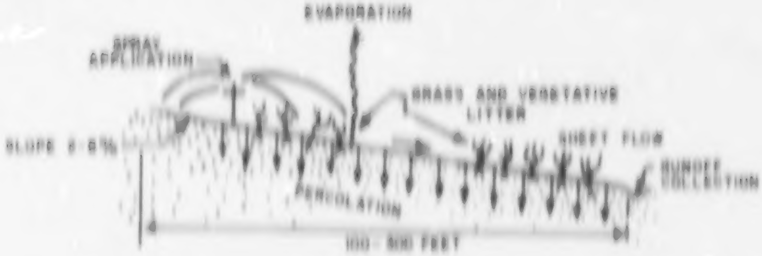
The principal mechanisms for renovation of the effluent are filtration, volatilization, plant-uptake, ion exchange, and fixation. The relative importance of each of these

Table 55. MUNICIPALITIES IN THE UNITED STATES USING LAND APPLICATIONS OF WASTE WATER, AND THE POPULATION SERVED.(53)

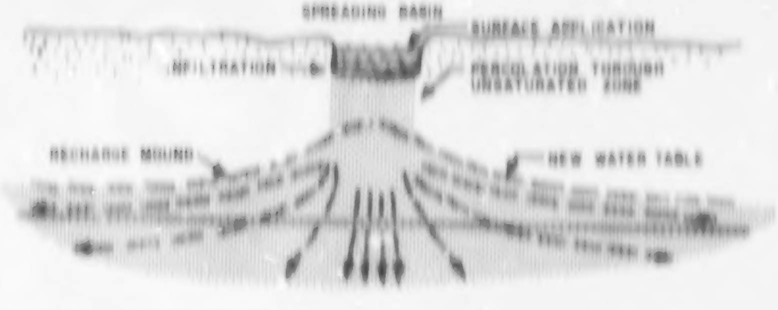
Year	Number of municipalities	Population served (millions)
1940	304	0.9
1945	422	1.3
1957	461	2.0
1962	401	2.7
1968	512	4.2
1972	571	6.6


EVAPORATION
VEGETATIVE COVER
SPRAY OR SURFACE APPLICATION
ROOT ZONE
SUBSOIL
SLOPE VARIABLE
DEEP PERCOLATION
UNDERDRAIN RECOVERY IN SOME CASES

SPRAY IRRIGATION


EVAPORATION
SPRAY APPLICATION
GRASS AND VEGETATIVE LITTER
SLOPE 2-8%
SHEET FLOW
RUNOFF COLLECTION
PERCOLATION
100 - 300 FEET

OVERLAND FLOW


SPREADING BASIN
SURFACE APPLICATION
INFILTRATION
PERCOLATION THROUGH UNSATURATED ZONE
RECHARGE MOUND
NEW WATER TABLE

RAPID INFILTRATION

Figure 45. Methods of land disposal of waste water.[154]

renovative mechanisms for each of ten waste water constituents varies for spray irrigation (Table 56), overland flow (Table 57), and rapid infiltration (Table 58).156)

There are no methods for land disposal of waste waters that can be routinely applied to every section of the U. S. Each site considered for use must be designed from information on the local climatologic, soil, geologic, and hydrologic conditions. Beyond this, an assessment of site suitability and design requires the interaction of geologists, sanitary engineers, hydraulic engineers, hydrologists, agronomists, soil scientists, irrigation engineers, virologists, health scientists, land planners, water resource planners, and social planners.157)

Climatological factors to be considered in site selection are temperature, precipitation, and wind speed and direction. Temperature affects the rate of evapotranspiration, the rate of infiltration, the renovation efficiency during winter months, the length of the growing season, and the microbiological activity within the soil. Precipitation affects the rate of application of the effluent and causes soil saturation and overland runoff of unrenovated effluent. Wind speed and direction can influence the drifting of aerosols and odors which may cause health problems.157)

The two most important soil characteristics influencing site selection are the ability to accept the applied effluent at the desired rate on a long-term basis and the ability to provide the desired renovation through the continued presence of chemically and physically active constituents. Each land disposal technique has its own soil drainability requirements. Overland flow works successfully on low permeability soils because most of the renovation takes place within the upper 5.1 cm (2 in) of the soil. Spray irrigation requires soils of moderate permeability so that water will be retained for crop uptake. Rapid infiltration requires soils with high permeability so that large quantities of the waste water effluent can be applied to a small land area.157) Figure 46 indicates the land disposal techniques and the corresponding ranges of liquid loading rates generally suitable to various soil types.

The nature and amount of physically and chemically active constituents in the soil, principally clay particles, control the extent of nutrient fixation. Rapid infiltration requires coarse soils with limited capacities for chemical reactions. Soils which have only a moderate content of these constituents are most suitable for spray irrigation sites where nutrients must be available or released for crop-uptake. Overland flow, which does not require

Table 56. RELATIVE IMPORTANCE OF RENOVATION MECHANISMS - SPRAY IRRIGATION.(56)

	Plant Uptake	Fixation	Volatilization	Ion Exchange	Filtration
Biochemical Oxygen Demand	0	2	3	0	4
Settleable Solids	0	2	2	0	4
Nitrogen	4	1	4	1	0
Phosphorus	4	3	0	2	3
Heavy Metals	1	4	0	4	0
Organics	0	0[a]	4	0	1
Viruses	0	2	3	0	4
Bacteria	0	2	3	0	4
Total Dissolved Solids					
Cations	0	4	0	2	0
Anions	2	4	0	1	0

a) Fixation is significant for chlorinated and polynuclear hydrocarbons.

Scale: 0 to 4
"0" relatively insignificant
"4" major mechanism

Table 57. RELATIVE IMPORTANCE OF RENOVATION MECHANISMS - OVERLAND FLOW.[56]

	Plant Uptake	Fixation	Volatilization	Ion Exchange	Filtration
Biochemical Oxygen Demand	0	2	4	0	3
Settleable Solids	0	2	2	0	4
Nitrogen	2	1	4	1	0
Phosphorus	2	4	0	1	0
Heavy Metals	0	4	0	2	0
Organics	0	0	4	0	1
Viruses	0	2	4	0	3
Bacteria	0	2	4	0	3
Total Dissolved Solids					
Cations	0	4	0	0	0
Anions	0	4	0	0	0

Scale: 0 to 4
"0" relatively insignificant
"4" major mechanism

Table 58. RELATIVE IMPORTANCE OF RENOVATION MECHANICS - RAPID INFILTRATION(156)

	Plant Uptake	Fixation	Volatilization	Ion Exchange	Filtration
Biochemical Oxygen Demand	0	2	2	0	4
Settleable Solids	0	2	2	0	4
Nitrogen	0	0	4	0	0
Phosphorus	0	4	0	0	0
Heavy Metals	0	4	0	2	0
Organics	0	0	4	0	1
Viruses	0	2	1	0	4
Bacteria	0	2	1	0	4
Total Dissolved Solids					
Cations	0	4	0	0	0
Anions	0	4	0	0	0

Scale: 0 to 4
"0" relatively insignificant
"4" major mechanism

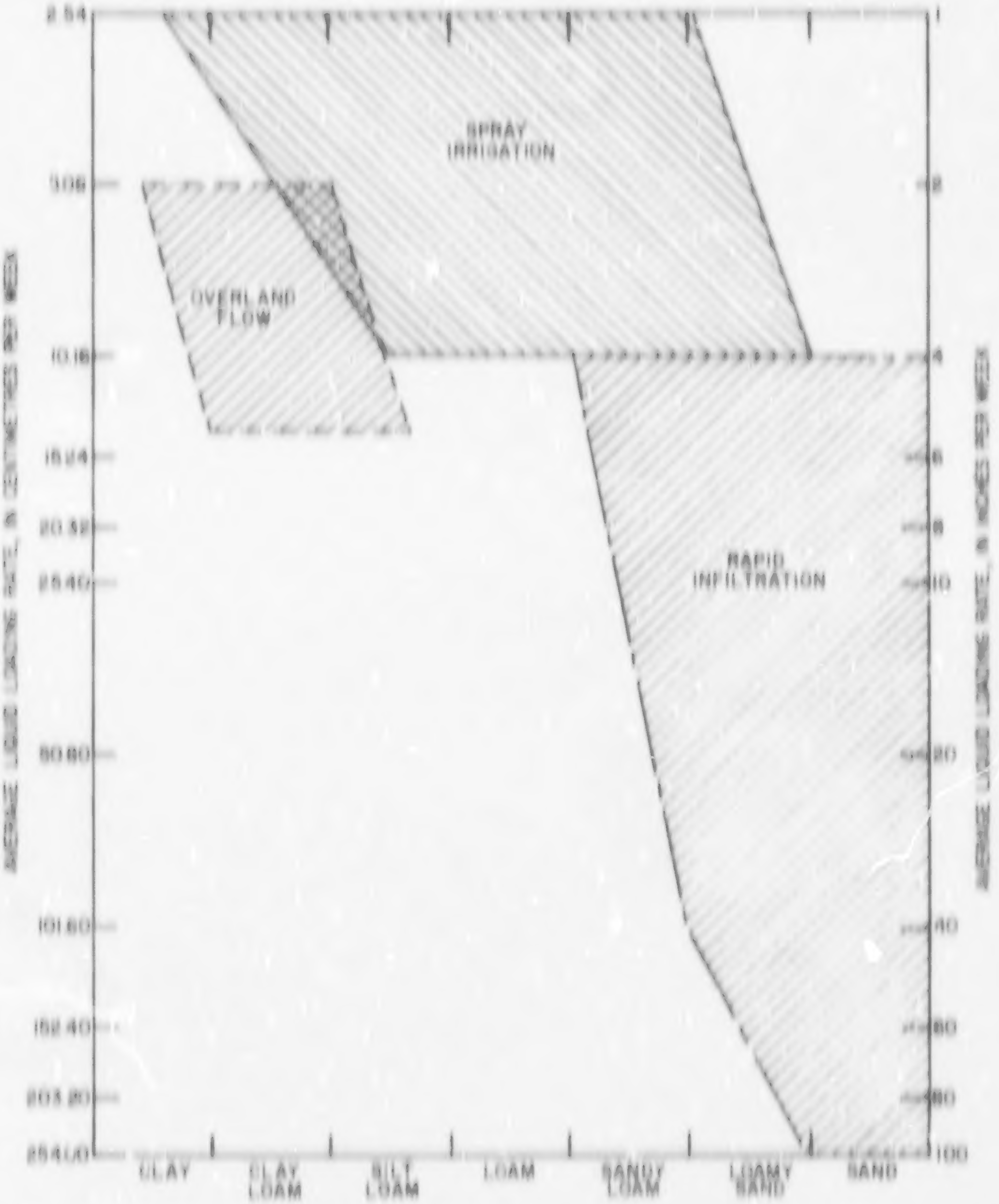


Figure 46. Soil type versus liquid loading rates for different land disposal techniques.(55)

substantial uptake of nutrients by vegetation, is a technique that needs a highly reactive clay soil to achieve renovation.157)

Some attempts have been made to offer general guidelines for the land disposal of waste waters. One principally endorsed recommendation is that a site-specific study be undertaken by a multi-disciplined team. In addition, relative to hydrologic considerations, the minimum depth to ground water must vary depending upon the method of disposal used. In the case of spray irrigation, the soil mantle must be thick enough to promote aerobic conditions for proper root development and to ensure renovation of the applied waste water. Minimum depth recommendations vary from 1.5 m (5 ft) for fine-grained soils to 3 m (10 ft) for coarser soils.154) For application by overland flow, water budget studies have shown that as much as 21 percent of the applied waste water may be lost to deep soil percolation.158) A minimum of 1.5 m (5 ft) is recommended between the ground surface and the water table.156) Application by rapid infiltration requires a very thick soil layer between the ground surface and the water table if renovation is to succeed. In this type of application, high effluent loading rates will cause the formation of a recharge mound on top of the water table. This could decrease the effectiveness of renovation if the mound rose too close to the land surface. Therefore, a minimum separation of 4.6 m (15 ft) between the ground surface and the water table has been recommended.159)

Varied hydrogeologic factors influence site acceptability or the need to modify the site or the method of application of effluent; they are not foreseen until more detailed site studies are undertaken. Existing ground-water quality is an important factor. If the ground water is of high quality, limited application of effluent may be required to avoid degradation by partially renovated waste water. Where the ground water is of poor quality, it may be necessary to install an underdrain system to collect the purified effluent if its reuse is contemplated.157) Also, the location of disposal sites in areas of fractures or cavernous bedrock can cause contamination if the soils are overloaded physically, chemically, or biologically by the waste water.

Site failures occur because the waste-water loading rate has exceeded the acceptable level. The loading rate has three components: hydraulic, organic, and nutrient. In a recent report by J. P. Hartigan, a series of hypothetical design problems were developed for each of the three waste water disposal methods taking into account the impact of the different loading components. Emphasis is placed on the necessity of knowing the nature of the effluent that is to be delivered to the site in order to calculate loading rates and size of the treatment area. In general, the size of the treatment area is inversely proportional to the waste water loading rate. There are approximate ranges of average loading rates with area requirements for each of the disposal techniques. They are presented in Table 59 for comparative purposes.[157]

Other factors which must be considered in the design of a disposal system are the "wetting" and "drying" schedules and the storage capacity. The wetting period should not overstress the system nor bring about anaerobic conditions. Intermittent drying is required to maintain design loading rates and renovative capacities. Excessive rainfall or frozen ground will inhibit infiltration, so a storage lagoon is needed. Such a facility should possess the following site characteristics: soil, topographic, hydrologic, and geologic conditions that will permit long-term storage of the waste water without degrading the local ground-water quality.[157] If such conditions do not exist to effectively protect the ground water, artificial seals or liners must be used in the storage lagoon.

Land disposal of waste water can pose a significant threat to ground-water quality when little renovation takes place before the waste water enters the ground-water system. The rapid infiltration method involves the highest probability of ground-water contamination; spray irrigation, a moderate probability; and overland flow, a slight probability.[160] Table 60 is a summary of ground-water contamination likely to occur from land disposal of waste waters. Although the overland flow method is not included in the table, it should not be discounted as a potential method of contaminant introduction. As mentioned earlier, as much as 21 percent of the applied waste water can be lost to deep soil percolation when utilizing the overland flow method.[158] If an overland flow system functions on more permeable soils than should be used, it will contribute fluids to the water table.

Case Histories

Near Tallahassee, Florida, an experimental spray irrigation disposal site utilizing secondarily-treated sewage has been in operation since 1966. Development of this method of waste-water disposal resulted from the need to decrease the flow of nutrients into Lake Munson, south of Tallahassee (see Natural Bodies of Surface Water section for a more detailed discussion).

Table 59. COMPARISON OF THE AVERAGE LOADING RATES AND TREATMENT AREA REQUIREMENTS FOR EACH OF THE METHODS OF LAND DISPOSAL OF WASTE WATER.157)

	Spray Irrigation	Overland Flow	Rapid Infiltration
Average Loading Rates			
centimetres/week	1.27-10.2	5.08-14.0	9.14-304.8
inches/week	0.5-4.0	2.0-5.5	3.6-120
Treatment Area Requirements			
hectares	208-26.1	52.2-19.0	29-0.89
acres	516-64.6	129-47	71.6-2.2

Table 61. SUMMARY OF CONTAMINATION LIKELY FROM LAND DISPOSAL OF DOMESTIC WASTE WATER.[160]

Parameter	Spray Irrigation	Rapid Infiltration
Nitrogen	Nutrients that are not used by plants or fixed in the soil can leach to ground water	Significant quantities passed to ground water at most sites
Phosphorus	Leaching of excess phosphorus is rare occurrence. Organic and clay soils absorb practically all of the phosphorus	Removal may be limited because granular soils are used
Organics	Usually broken down by microorganisms and used by plants. Can appear in ground water when application rate is highest or when in open soil, such as sand or gravel, with a high application rate	Evidence is that little organic matter reaches ground water
Trace Element	Toxic compounds can be changed by the chemical reaction of cation exchange and can be rendered non-toxic by bacteria. Chemical precipitates formed can be leached out, however	Retention may be limited due to granular nature of soils
Total Dissolved Solids	Leaching can occur and build-up is possible	Build-up is possible
Enteric Organisms	Usually are removed or die out and do not reach ground water especially if water table is kept low	Spread of bacteria and viruses by insects or percolating water is of concern but unlikely under proper soil conditions

Secondarily-treated sewage effluent was applied to 15.6 ha (38.5 acres) of forested and cropped sites by a number of spray irrigation techniques. A detailed study of the effects of irrigation on ground-water quality was conducted during the period March, 1972 to June, 1974. The results indicate that ground-water contamination by nitrate is taking place downgradient from the disposal site. The outline of the effluent plume and its movement based on chloride concentrations in ground water is shown in Figure 47; the physical arrangement of the site and the observation wells are also illustrated. Chloride and nitrate-nitrogen data indicate that there was some lateral movement of the partially renovated effluent, but most of the effluent moved downward at least 82 m (270 ft), as illustrated in Figure 48. The contaminant movement is attributed to the application of about 43 m (140 ft) of effluent onto the forested area from March, 1972 to June, 1974. Chloride and nitrate-nitrogen concentrations equivalent to those in the undiluted effluent were found in ground water from depths of 46 to 82 m (150 to 270 ft) at the downgradient edge of this heavily-sprayed area. Effluent-percolate has moved from the spray irrigation site at the rate of about 730 m (2,400 ft) per year. As of June, 1974, the ground water beneath about 56.7 ha (140 acres) had increased nitrate-nitrogen and chloride concentrations. This plume may extend downgradient from the site as far as 1,200 m (4,000 ft).161)

Figure 49 shows the variation of NO_3-N with time at the site of Well 5 (see Figure 47 for location). This illustrates that lateral movement of NO_3-N has occurred; however, concentrations are less than those at greater depths in Well 23 (Figure 47). It appears that the rate of increase of NO_3-N is leveling off in Well 5.161)

The principal cause of the contamination seems to be an overloading of the system. Effluent is being applied to a very small area at the rate of approximately 35.6 cm (14 in.) per week. The process taking place at the site is nitrification, resulting in massive nitrate contamination. Nitrate-nitrogen concentrations have risen as high as 37 mg/l (163 mg/l as NO_3).161) The contaminated water is moving southward, rendering the Floridan Aquifer unuseable in that direction. Nearby well pumpage could induce movement of the contaminated water toward those wells.

In St. Petersburg, Florida, a waste disposal site utilizing the spray irrigation method was tested. (Salt-water encroachment in the downtown city wells had occurred in the 1920's and there are no public-supply wells in St. Petersburg. Competition for water supply is so intense in the adjoining

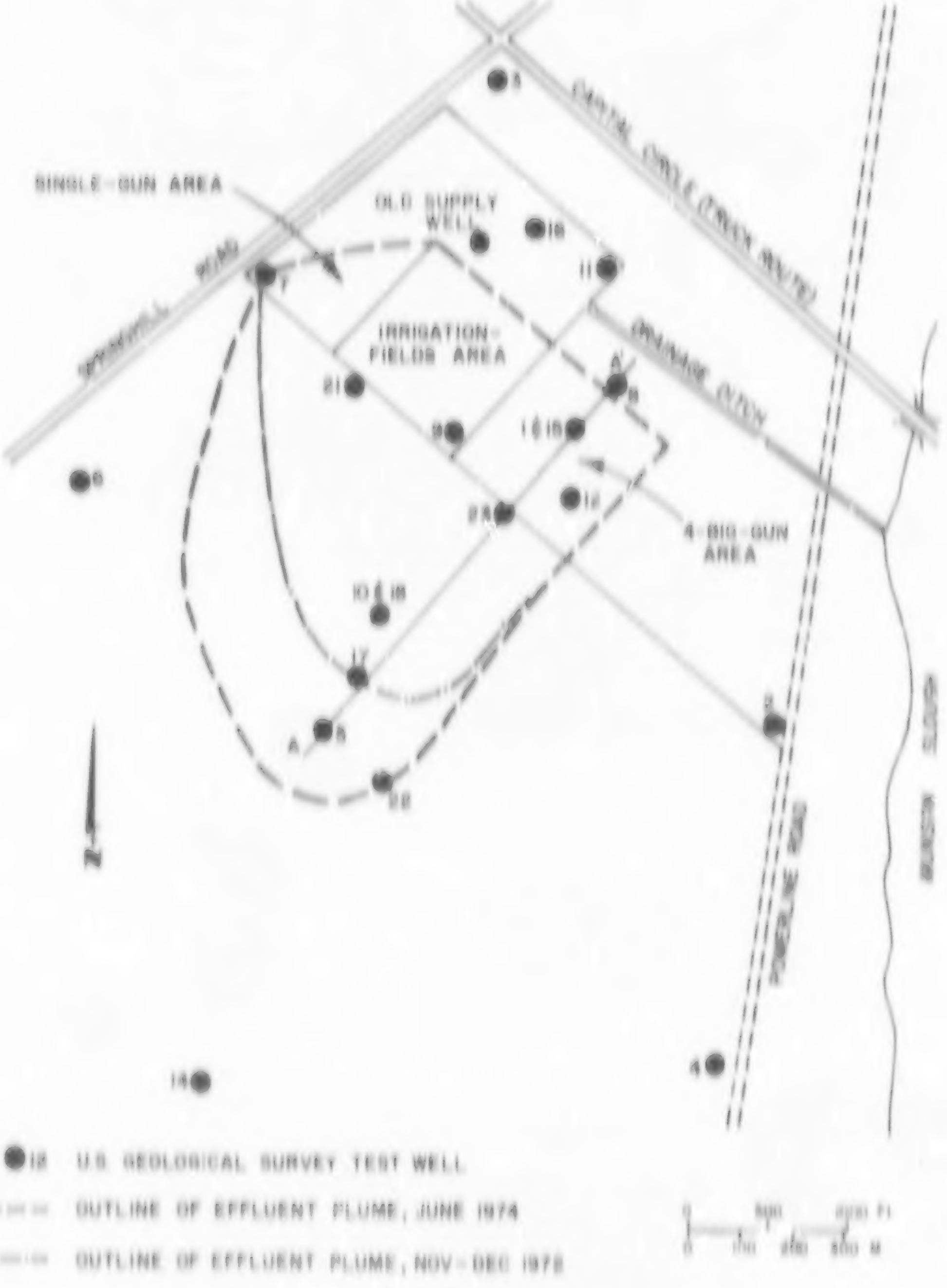

SINGLE-GUN AREA
OLD SUPPLY WELL
IRRIGATION-FIELDS AREA
4-BIG-GUN AREA
SPRINGHILL ROAD
CAPITAL CIRCLE (TRUCK ROUTE)
DRAINAGE DITCH
POWERLINE ROAD
MUNSON SLOUGH
N
A
A'
3
16
11
7
21
9
1 & 15
8
6
12
23
10 & 18
17
5
22
2
14
4
● 12 U.S. GEOLOGICAL SURVEY TEST WELL
OUTLINE OF EFFLUENT PLUME, JUNE 1974
OUTLINE OF EFFLUENT PLUME, NOV-DEC 1973
0 500 1000 Ft
0 150 300 M

Figure 47. Outline of the effluent plume based on chloride concentrations in ground water, Tallahassee, Florida, spray-irrigation site.[161]

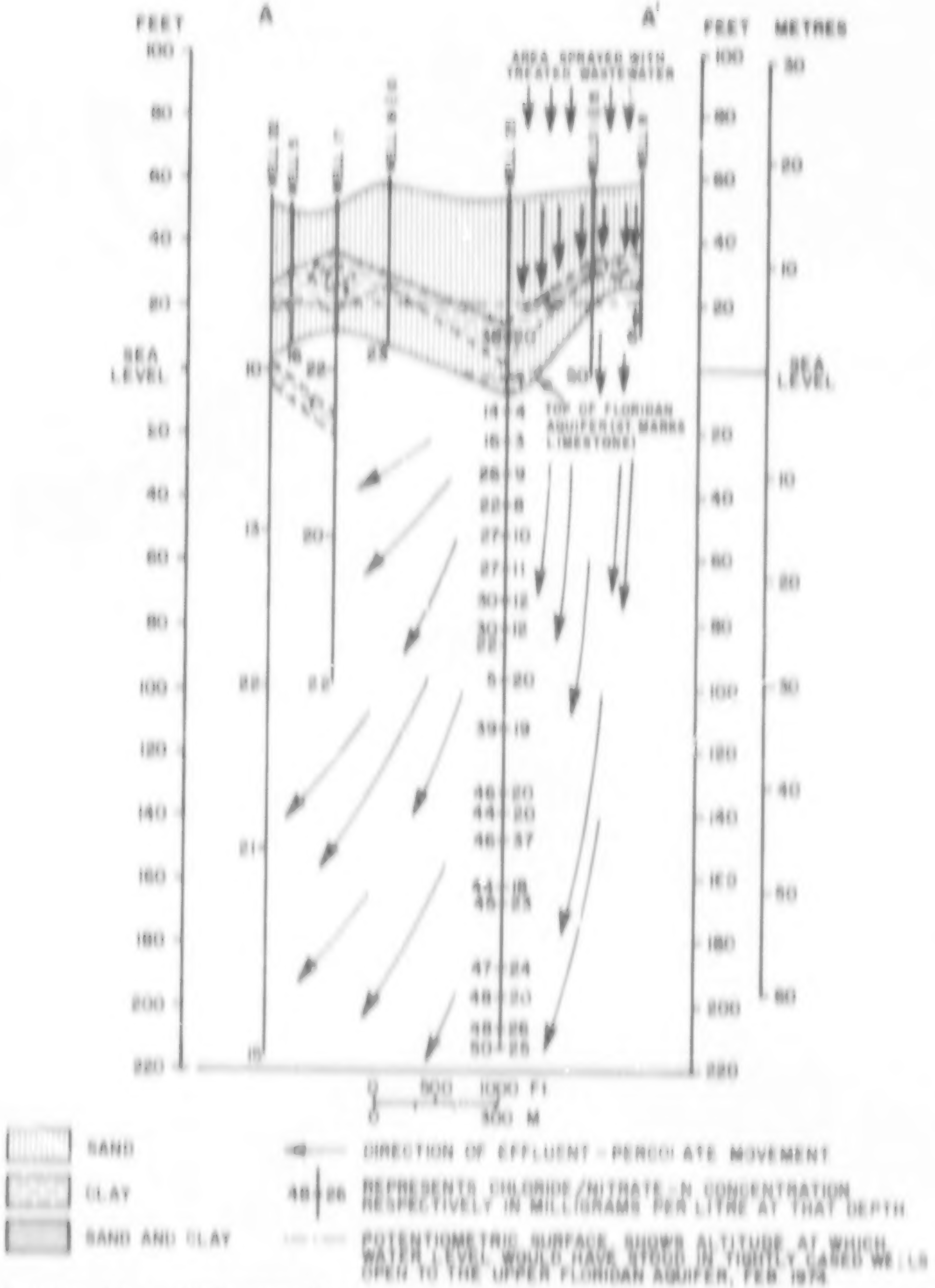

FEET
A
A'
FEET
METRES
AREA SPRAYED WITH TREATED WASTEWATER
100
80
60
40
20
SEA LEVEL
20
40
60
80
100
120
140
160
180
200
220
30
20
10
SEA LEVEL
10
20
30
40
50
60
TOP OF FLORIDAN AQUIFER(ST MARKS LIMESTONE)
14 4
16 3
26 9
22 6
27 10
27 11
30 12
30 12
5 20
39 19
46 20
44 20
46 37
45 23
47 24
48 20
48 26
50 25
0 500 1000 FT
0 300 M
SAND
CLAY
SAND AND CLAY
DIRECTION OF EFFLUENT - PERCOLATE MOVEMENT
48 26 REPRESENTS CHLORIDE/NITRATE-N CONCENTRATION RESPECTIVELY IN MILLIGRAMS PER LITRE AT THAT DEPTH
POTENTIOMETRIC SURFACE, SHOWS ALTITUDE AT WHICH WATER LEVEL WOULD HAVE STOOD IN TIGHTLY CASED WELLS OPEN TO THE UPPER FLORIDAN AQUIFER, FEB 1974

Figure 48. Hydrogeologic section A-A', Tallahassee, Florida, spray-irrigation site.161)
(See Figure 47 for location)

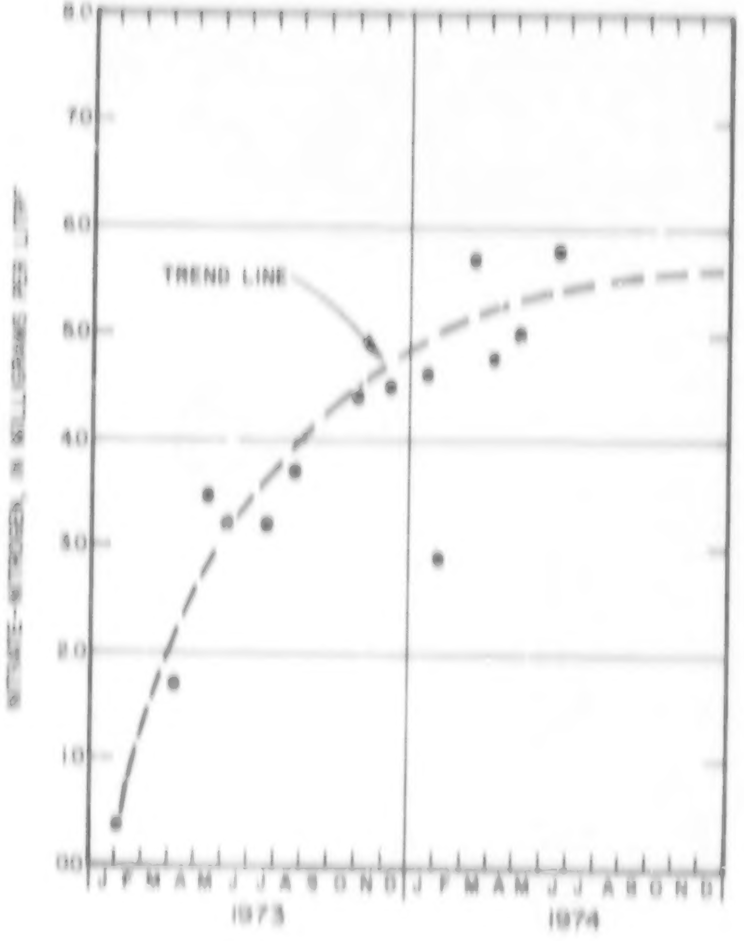


Figure 49. Variation of nitrate-nitrogen with time at Well 5, Tallahassee, Florida spray-irrigation site,161) (See Figure 47 for location)

counties where newer supply wells are located that waste-water renovation and reuse is being considered to supplement present local supplies.) The nutrient constituents in the waste water delivered to the site were principally in the form of organic nitrogen (2 to 6 mg/l), ammonia nitrogen (14 to 16 mg/l), and total phosphorus (2.6 to 4 mg/l). The content of nitrate and nitrite nitrogen was less than one percent of the total nitrogen. The waste water also contained approximately 110 mg/l chloride.162)

The spray-irrigation site is underlain by three hydrogeologic units: an uppermost shallow aquifer of fine sands and clayey sands; a middle confining unit of pale green, dense, sandy clay; and the lower limestone and dolomite of the Floridan Aquifer. The soil immediately under the site is a fine-grained sand low in organic matter.162)

Batteries of wells constructed in and near the spray irrigation site were used to measure water levels and to collect water samples. Each battery consists of several wells; 0.6, 1.5, 3.0, 4.6, and 6.1 m (2, 5, 10, 15 and 20 ft) deep. One battery also had a well 15.2 m (50 ft) deep. Additionally, an underdrain system was installed 1.5 m (5 ft) below land surface. Application rates of 5.1, 10.2, and 27.9 cm (2, 4, and 11 in.) per week were tried, and water samples were taken at the end of each period of irrigation.162)

Table 61 illustrates the extent of NO_3-N buildup in the ground water and the drainage system effluent. An increase in chloride content from 25 to 120 mg/l occurred at the 3 m (10 ft) depth and from 9.2 to 120 mg/l at the 6.4 m (15 ft) depth. Total phosphorus content increased after each period of irrigation, with the greatest increase occurring after the 27.9 cm (11 in) per week rate of application. The original total phosphorus contents at the various depths ranged from 0.0 to 0.84 mg/l; and, after the sequence of effluent application, the range was from 0.5 to 5.4 mg/l.162)

The ground water under the spray irrigation site is not being utilized at present. An increase in the chemical concentrations of selected parameters was observed. However, contamination of the Floridan Aquifer is not likely because of the confining layer which separates it from the shallow aquifer. It is possible that there is an acceptable loading rate for these soils.

Future Trends

The use of land disposal of municipal waste water will continue to increase as communities attempt to meet the

Table 61. CONCENTRATIONS OF NITRATE-NITROGEN IN GROUND-WATER SAMPLES FROM WELLS AT A ST. PETERSBURG, FLORIDA, SPRAY IRRIGATION SITE, IN mg/l. 162)

Sampling Point	Before Irrigation	During Irrigation @ 5.1 cm/wk (2 in/wk) 9/19-10/2/72	 @ 10.2 cm/wk (4 in/wk) 10/5-11/14/72	 @ 27.9 cm/wk (11 in/wk) 1/29-3/22/73
1.5-m (5-ft) well	1.4	a)	8.0	22
3-m (10-ft) well	0	5.06	0.19	8.1
4.6-m (15-ft) well	0	0	0	0.26
6.1-m (20-ft) well	0	0	0.07	0.35
15.2-m (50-ft) well	0.02	a)	a)	0
Underdrain System	----	3.3	0.97	3.9

a) No sample collected.

higher water quality standards adopted as national goals through the 1972 Amendments to the Federal Water Pollution Control Act. This expanded use of spray irrigation, overland flow, and rapid infiltration as methods of waste-water renovation can cause further occurrences of ground-water contamination.

It should be pointed out that certain methods of waste-water disposal on land do not necessarily cause ground-water contamination. However, without the wide variety of personnel needed to properly design the system and a program of constant supervision and maintenance, contamination will occur in many cases. Communities desiring such a facility will have to employ consultants qualified to follow the multi-discipline approach. The design and operation of land disposal centers requires the interaction of geologists, sanitary engineers, hydraulic engineers, hydrologists, agronomists, soil scientists, irrigation engineers, virologists, health scientists, land planners, water resource planners, and social planners.

Within the next few years a considerable amount of data will be generated in reports concerning sites in operation at the present time. Rather than the conclusions being used to standardize methods for designing new sites, they should be used as guidelines only. However, encouragement is given by the fact that consultants who would have traditionally handled such a project on their own are now expanding the capabilities of their professional staff or are entering into cooperative arrangements with other specialists.

MISCELLANEOUS SOURCES

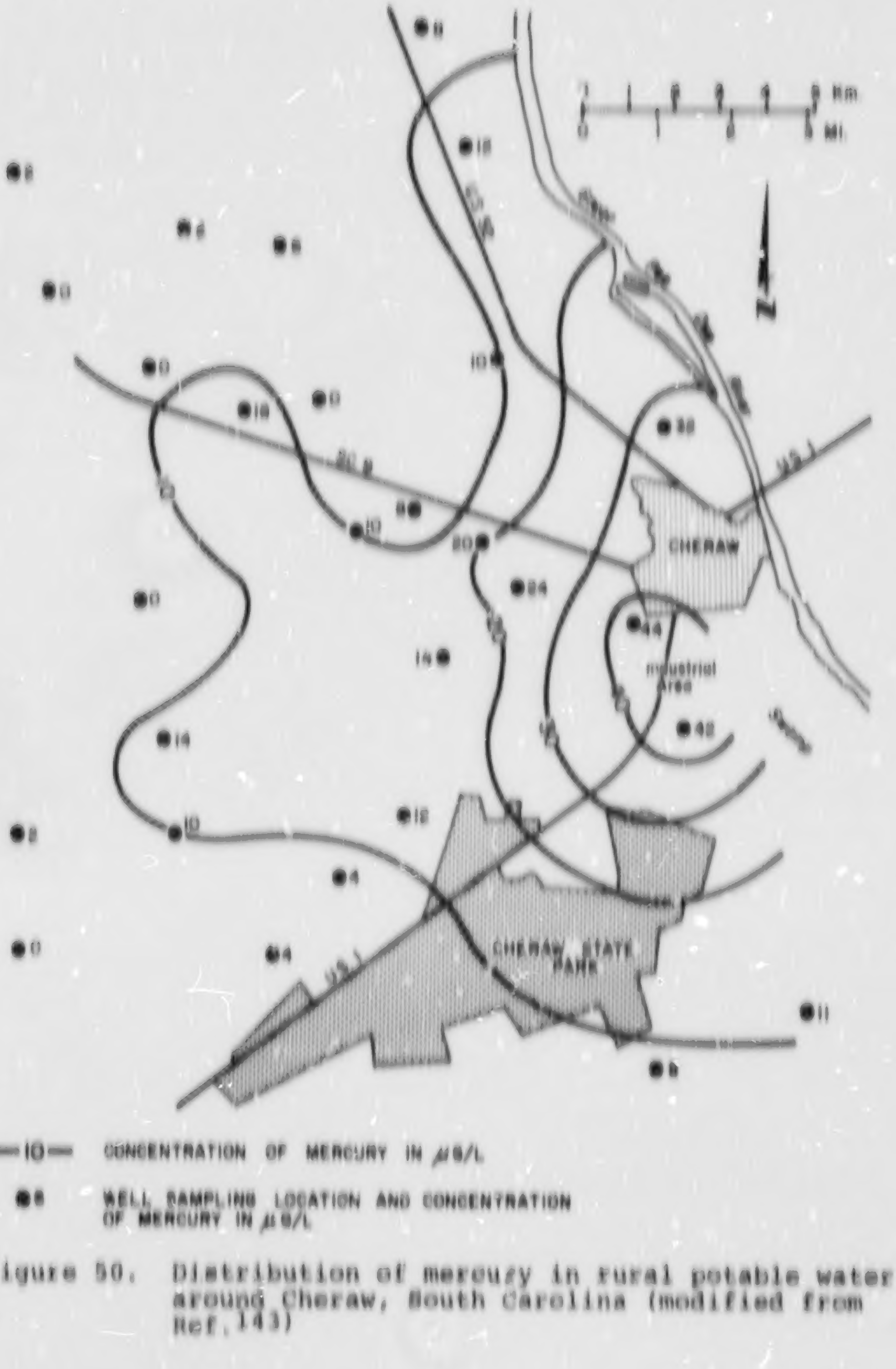
In modern times, man's activities have become so varied and complex that many unforeseen cases of ground-water contamination have occurred. This report summarizes the sources of contamination that commonly cause problems in the Southeast. However, it is by no means a complete list of actual and potential sources. All documented cases of contamination which have occurred anywhere in the world could be used to forecast potential sources of contamination in the southeastern United States. The ground-water geologist continually encounters new types and methods of contamination, even though the mechanisms are the same. Listed below are some case histories of ground-water contamination difficult to classify because the actual cause is unknown or because it may be considered a one-time event.

Case Histories

In Chesterfield County, South Carolina, 217 farm and rural community water supplies were sampled to assess the quality of water. Higher concentrations of nitrate, phosphate, chloride and arsenic were found in water sources located near septic tanks, and higher concentrations of cadmium and lead occurred in samples taken from residences with older plumbing. There was, however, no explanation for the high concentrations of mercury found in the ground water. Mercury was found in 80.9 percent of the water supplies sampled, of which 13.2 percent exceeded 10 μg/l. Figure 50 is a map of the Cheraw, South Carolina, area which shows an increase in mercury content in and around an industrial area south of town.143) Further investigation to locate the precise source of mercury is in progress. It is unlikely that surface spills are the cause. Widespread areal distribution suggests that airborne dispersion of plant emissions could be the primary cause. The distribution may be the result of particulate fallout and subsequent leaching of the mercury by acidic rainwater. A rather large area is involved and no clear migration pattern is distinguishable based on the flow pattern of water in the aquifer. The trend of the Upper Cretaceous sands northeast to southwest across the area shows no influence on the distribution of mercury contaminant as would be expected if it had been a surface spill.

A recent Environmental Protection Agency survey of suspected carcinogens in drinking water disclosed that there were high levels of chlorinated organics in the ground waters of the Preston-Hialeah well fields in Dade County, Florida.163) The source of the chemicals is unknown, although the concentration of chlorinated organics is greater downgradient from the 58th Street Landfill than upgradient. It is uncertain whether the source of the carcinogens is from the chlorination of substances in the leachate or of natural organics within the shallow aquifer.164)

Road construction and associated blasting of consolidated rock probably cause considerably more local contamination of ground water than was indicated by the cases uncovered in this study. Of particular concern are those incidents related to bacterial contamination. In Clifton Forge, Virginia, about 25 percent of the water-supply wells became contaminated when bacteria entered the aquifer through fractures in the rock; the apparent cause of the fractures was the blasting in the area. The jarring of the rocks caused "contaminants of all sorts" which have collected on the ground surface for years to enter the ground-water


0 1 2 3 4 5 Km
0 1 2 3 Mi
N
CHERAW
Industrial Area
CHERAW STATE PARK
U.S. 1
U.S. 1
10
20
24
44
42

—10— CONCENTRATION OF MERCURY IN µG/L

● 8 WELL SAMPLING LOCATION AND CONCENTRATION OF MERCURY IN µG/L

Figure 50. Distribution of mercury in rural potable water around Cheraw, South Carolina (modified from Ref.[143])

system.165) Similar events occurred in northern Florida during and after construction of Interstate Highway 10. Well owners reported muddying of water in wells and springs.166)

In 1952, city water officials of New Bern, North Carolina noticed that the chloride content of two of their eight wells had risen from less than 10 mg/l to 90 and 405 mg/l respectively. These wells had been recently installed as replacements for abandoned supply wells contaminated by salt-water encroachment from the Neuse River. However, it was determined that the source of the chlorides was the downward percolation of calcium and sodium chloride from the effluent from a water-treatment plant; it had been discharged into a ditch which ran between the two wells. Near the ditch, at a depth of about 3 m (10 ft), the chloride content of the ground water was 1,950 mg/l. A study of the calcium/magnesium ratios in the water samples provided further evidence that the source of contamination was the waste water from the treatment plant and not salt-water encroachment, as had occurred in the abandoned wells. Additionally, a three-month pumping test of a well showed a continuous decrease in chloride content. This is contrary to what would have been expected if the cause had been salt-water encroachment.167)

A fire destroyed a pesticide and fertilizer warehouse in Farmville, North Carolina, in June, 1971. Large volumes of water, estimated to be as much as 5,677,500 l (1.5 million gal), were used to extinguish the fire. Warehouse personnel, realising that runoff water would be highly toxic, dammed the nearby ditches to prevent flow to surface waters. The contaminated water was essentially confined to the property. A total of 61 different pesticides were stored in the warehouse with 54,107 l (14,295 gal) in liquid form and 95,755 kg (211,099 lb) in solid form at the time of the fire.

Such an incident had not occurred in North Carolina before, and a plan for a cleanup was not readily available. Various governmental agencies and industry groups were called in for advice and assistance. The critical nature of the situation was that not only surficial contamination was involved; deep municipal water-supply wells were located nearby. One well was located within 91 m (300 ft) of the contaminated area. The well was immediately shut off, and water samples were collected for pesticide analyses.

An estimated 378,500 l (100,000 gal) of contaminated runoff water was in a ponded area, and two pits, which were 30.5 m

(100 ft) long, 1.8 m (6 ft) wide, and 2.1 m (7 ft) deep, were constructed and lined with polyethylene. The water was then pumped from the ponded area into the pits.

A report by the North Carolina State Pesticides Program stated that bureaucratic and inter-agency arguments delayed decisions, and disposal of contaminated rubble and soil did not start until almost one week after the fire. A site located on Federal land 4.3 km (7 mi) to the northeast was chosen for disposal purposes because of the high ground-water levels in the Farmville area.

Two cells at the disposal site were prepared, each 30.5 m (100 ft) wide, 61 m (200 ft) long, and 0.3 m (1 ft) deep. A layer of dolomitic lime 153 mm (6 in) thick followed by a 10.2 cm (4 in) thick layer of hydrated lime was placed on the floors of the cells. The solid waste from the pesticide and fertilizer warehouses was landfilled into one cell. The material, compacted to a 0.9 m (3 ft) thick layer, was covered with a minimum of 0.9 m (3 ft) of compacted clay mounded with sufficient slope to allow runoff. The liquids at the site were hauled by tanker trucks to the disposal site where they were mixed with lime and clay and buried in the second cell.

Shallow wells were drilled by the Ground-Water Division of the North Carolina Department of Water and Air Resources near the site of the fire and near the disposal site for monitoring purposes. The Farmville municipal wells were to be monitored by the North Carolina State Board of Health.168)

Samples collected from monitor wells at the fire and disposal sites during the period 1971-1975 have not contained pesticides. As was mentioned previously, only 378,500 l (100,000 gal) of the estimated 5,677,500 l (1.5 million gal) of water used to fight the fire were recovered; the location of the remainder of the contaminated water is unknown. Continued monitoring of both sites is recommended.169)

Future Trends

As previously stated, ground-water contamination occurs because of actions by our varied and complex society. Unforeseeable circumstances may cause many sources of ground-water to be affected or rendered unuseable. However, the recent awareness of such possible contamination has caused investigators to anticipate many problems. Contingency and emergency plans exist and they are ready to be implemented. In some states teams have been formed to deal with emergency environmental problems. Both industry and local governments have been made aware of the existence of such teams, and contact has been made simple. Such an approach to safeguard our ground-water resources should be encouraged.

GROUND-WATER DEVELOPMENT

Ground-water development can cause physical, chemical or biological effects on the environment. In an area underlain by carbonates, the lowering of the water table may result in the development of sinkholes or areas of subsidence; these are physical effects. Land surface collapse or subsidence may result directly in pollution by causing cracks or ruptures in pipelines or storage tanks. It may result in pollution indirectly by providing a route for pollutants to enter the ground-water system.

Chemical effects can result from the lowering of the water table, exposing minerals to an oxidizing environment. The oxidation products may be leached downward by percolating rain water; subsequent recovery of the water level may result in a highly mineralized solution entering the ground-water system. Salt-water encroachment is both a physical and chemical effect; that is, saline water is moved from one place to another in an aquifer and results in deterioration of the chemical quality of the water. Biological effects can result from an increase or decrease of bacterial activity when physical and/or chemical changes cause an imbalance in the ground-water system.

In the Southeast, intrusion of brackish or saline water into fresh-water aquifers is a widely recognized form of contamination resulting from ground-water development. Under natural conditions, aquifers may contain saline water close to the surface in coastal areas or at depth in areas further inland. If pumpage of ground water from wells is great enough the original hydraulic gradient may be altered enough to allow sea water to advance inland or brackish water at depth to upcone at the pumping center. Large-scale movement of salt water through an aquifer can occur, displacing fresh water either permanently or temporarily. Some of the mechanisms that can aggravate the problem include: construction of fresh-water drainage canals connected to coastlines, bays, or tidal streams; dredging of relatively impermeable sediments from the bottoms of bays or tidal streams; and presence of leaky or corroded well casings.

Salt water occurs naturally in water-table and artesian aquifers in some locales along the Atlantic and Gulf Coasts. The fresh water-salt water boundaries of the relatively shallow aquifers of Pleistocene and Holocene ages closely correspond with the present-day shoreline. However, in some of the deeper aquifers of Tertiary and Cretaceous ages, natural salty water may occur many miles inland. At some localities near the shore, deep wells may penetrate alternating zones of fresh and salty water. In these inland areas, the presence of natural saline water may be related to one or more of the following: retention in rock formation of the salty water in which the formation was deposited (connate water); solution of salts from the formation or from adjacent formations; and subsequent exposure to another source of salt water after the deposition of the formation.[170]

Water wells are not normally considered sources of ground-water contamination. However, there are means through which a well can become a vehicle for the introduction of contaminants. Some of them are: corroded or ruptured casings; well screens or open boreholes interconnecting two separate aquifers; improperly sealed surface casings; and flowing artesian wells. An analysis of reported waterborne disease outbreaks in the U. S. during the period 1946 to 1970 shows that contaminated ground-water supplies were responsible for 44 percent of the cases. Over half of these waterborne disease outbreaks are attributed to improper well location and construction.[171] In these instances, wells can serve as a conduit for pollutants to migrate from one aquifer to another or from the land surface to an aquifer. A single well can be the focal point of contamination for the areas immediately surrounding the well; contamination can be more widespread in a locality containing many wells.

Case Histories

One case history of ground-water contamination due to ground-water development concerned a municipal well in Selma, North Carolina. In September 1953, the well was drilled to 91 m (300 ft) in material consisting of sericite schist and disseminated pyrite. Until October, 1954, the well was pumped continuously; this resulted in a drawdown of 37 m (120 ft). The water had a relatively high iron content and a low pH, but it was potable and there was no change in quality during the pumping period. Then, for about four months, the well was not pumped, and the water returned to its natural level. In February, 1955, the well was pumped again; the water was very acidic (pH of 2.5) and contained abnormally high quantities of iron and sulfate (approximately 365 mg/l and 1,330 mg/l, respectively). The change was attributed to the oxidation of pyrite within the cone of depression and the subsequent solution of iron and sulfate when the water level had recovered to its pre-pumping level. The problem was alleviated by pumping the well on a continual basis.172)

Lowering the water table, or the potentiometric surface of a confined aquifer, in carbonate material increases the potential for the development of sinkholes. Generally, sinkholes develop during periods of heavy rainfall; they often occur in areas where the surface environment has been modified. In Alabama there are approximately 4,000 man-related sinkhole collapses.173) Within and around one industrial subdivision in Birmingham, it is estimated that, from 1963 to 1970, 200 collapses and subsidence areas developed over less than 1.3 sq km (0.5 sq mi).174)

The formation of a sinkhole may directly cause ground-water pollution, or it may provide a conduit for pollutants to easily enter the aquifer. In the vicinity of Birmingham, sinkhole development ruptured a major sanitary sewer line and resulted in the introduction of raw sewage into a quarry. The sinkhole was caused by ground-water withdrawals which had lowered the water table 42.7 m (140 ft). During the investigation of the problem, it was concluded that sinkhole development is a major cause of ground-water pollution, and it will continue to be a problem in that area.174)

The city of Columbiana, Alabama, had two minicipal-supply wells which withdrew water from a limestone aquifer. Continuous pumping of the wells created coalescing cones of depression. Subsequent problems related to land subsidence included: development of cracks in the filter plant reservoir; threatened collapse of a 24,600 l (6,500 gal) elevated storage tank; valve breakage on a butane storage tank; and development of foundation problems in a housing project. In addition, even though the water supply from the wells waw adequate, the water often became turbid after periods of rain. This was an indication of surface connection with the aquifer. The State Geological Survey studied the problem and recommended that new wells be installed 12.9 km (8 mi) southeast of the town and that the existing municipal wells be abandoned.175)

Intrusion of salty water is almost always a very slow process. In some localities where encroachment has taken place, records show that many decades elapsed before the salt content of the ground water rose to a point where it exceeded the recommended limit. Few cases of broad regional encroachment are known in the study area. Table 62 is a summary of known ground-water contamination cases in the Southeast as a direct result of salt-water intrusion. It is

Table 23 SUMMARY OF CASE HISTORIES ON SALT-WATER INTRUSION (17,55,127,178-21)

Location	Aquifer	Nature of Problem	Remedial Action
Alabama			
Mobile-Gulf Coast Region	Pleistocene : Sand & Gravel	Overdevelopment of well field and well point dewatering system for excavation caused lateral intrusion from Mobile River	Pumping curtailed
Marengo County	Not known	Saline water migrated upward within a fault	Well field relocated
Florida			
Escambia County	Sand and Gravel	Heavy pumping of industrial wells near bayou Chico caused lateral intrusion	Replacement wells drilled further from bayou
Escambia County	Sand and Gravel	Pumping from industrial well field reversed gradient and salt water migrated laterally from Escambia River	Unknown
Okaloosa County	Floridan	Decline in hydraulic head of Upper Floridan Aquifer caused upward migration of salt water through abandoned wells and confining beds	Abandoned wells partially or completely plugged
Bay County	Secondary Artesian	Saline surface water leaked downward from bays contaminating two wells completed in artesian aquifer	Wells abandoned
Nassau County Fernandina Beach	Floridan	Artesian pressure decline resulted in vertical and horizontal intrusion	Unknown
St. John's County	Floridan	Heavy pumpage caused salt water to upcone	Unknown
Flagler County	Floridan	Highly mineralized water migrated upward due to increase in pumping	Unknown

Table 52 (cont): SUMMARY OF CASE HISTORIES ON SALT-WATER INTRUSION[17,55,127,178-213]

Location	Aquifer	Nature of Problem	Remedial Action
Flagler County Flagler Beach	Shallow	Municipal well field was recharged with salt water from Floridan Aquifer	Unknown
Volusia County Ormond Beach	Floridan	A decline in the potentiometric surface resulted in an increase of chlorides in water from 8 supply wells	Casing repaired
Volusia County Daytona Beach	Floridan	Salt water upconed under municipal well field	Unknown
Volusia County Port Orange	Floridan	Salt water upconing of saline wells	Pumping rate controlled
Seminole County Sanford area	Floridan	Heavy localized pumping resulted in upconing of saline water under city well field	Unknown
Orange County Cocoa Well Field	Floridan	Pumpage from municipal well field resulted in lateral and/or vertical intrusion (eastern part of the county)	Pumping curtailed
Brevard County	Floridan	Pumping for irrigation and municipal use resulted in upconing	Unknown
Indian River County	Floridan	Wells open in two zones allowed salt water to move into shallower section of aquifer due to higher head in lower zone	Unknown
Martin County	Shallow Water Table	Overpumpage of city wells caused encroachment from St. Lucie River	Pumpage terminated
Palm Beach County	Biscayne	Diversion of river water by irrigation canals caused salt water to extend inland resulting in increases in chloride content in wells	Well field abandoned

Table 62 (cont). SUMMARY OF CASE HISTORIES ON SALT-WATER INTRUSION.[17,55,127,176-213]

Location	Aquifer	Nature of Problem	Remedial Action
Pasco County	Floridan	Overpumpage of fresh water aquifer near coast caused migration of salt water into wells	Declared a water shortage area; tighter controls imposed
Pinellas County	Floridan	Increasing pumpage from well field resulted in salt-water intrusion	Abandoned wells in the area and relocated well field further inland
Sarasota County	Floridan	Well casings in shallow sands corroded; salt water entered well and moved down to deeper aquifer	Well casings replaced and grouted with cement
Charlotte County	Shallow	Lateral movement of salt water from Gulf and estuaries; upward vertical movement due in part to poor well construction and to abandonment	Changed well construction methods and began plugging abandoned wells
Lee County	Shallow and Floridan	Saline water from deep artesian aquifer moving up into overlying aquifer through open boreholes of abandoned wells	Program of plugging abandoned wells initiated
Hendry County	Floridan	Upward movement of residual saline water caused by intensive pumping and corroded well casings	Ceased ground-water pumping in the area
Palm Beach County	Biscayne	Dry spell in 1970-71 caused salt water wedge to migrate up canals and intracoastal waterways thus contaminating aquifer	Temporary termination of pumpage from some wells in well field
Broward County Ft. Lauderdale	Biscayne	Increasing drawdowns in municipal well field posed the threat of salt-water encroachment	A feeder canal was dredged to increase recharge to well field

Table 62 (cont). SUMMARY OF CASE HISTORIES OF SALT-WATER INTRUSION (17,55,127,176-213)

Location	Aquifer	Nature of Problem	Remedial Action
Broward County	Biscayne	Salt-water wedge has moved to within 0.8 km of public well field	Unknown
Broward County	Biscayne	Salt-water migration in coastal areas due to increase in pumpage and in canal construction	Salinity control structures built on major canals
Dade County Miami	Biscayne	Salt water moved up the Miami canal due to dry conditions; four wells in the area contaminated	Temporary dam constructed on the canal
Miami	Biscayne	Increased pumpage and dry conditions caused salt water migration around control structure; nearby wells were contaminated	Unknown
Miami	Biscayne	Heavy pumpage during drought caused salt water to move around control structure; aquifer contaminated locally	Unknown
Miami	Biscayne	Heavy pumpage during drought caused migration of mineralized water toward a municipal well field	Heavy rains raised water levels; thus no contamination of well field occurred
Miami	Biscayne	Heavy pumpage during drought caused sharp increases in chloride content in monitoring well	Pumpage from wells nearest the saline front was curtailed; water was pumped from Lake Okeechobee into the Miami canal to raise water levels in the well field area

Table 62 (cont). SUMMARY OF CASE HISTORIES ON SALT-WATER INTRUSION[17,55,167,178-213]

Location	Aquifer	Nature of Problem	Remedial Action
Collier County Naples area	Shallow	Lateral and vertical movement of salt water due to closely spaced and heavily pumped wells	Well field moved
Georgia			
Savannah area	Principal Artesian	Large ground-water withdrawal has resulted in potential lateral and upward movement of salty water; leaky well casings have caused local problems	None yet; intrusion has not affected major production wells
Brunswick area	Principal Artesian	Extensive ground-water development has caused vertical movement from residual salt water zones into aquifers in two areas; improperly cased wells or corroded casings cause local problems	Unknown
Mississippi			
Pascagoula area	Miocene (Pascagoula Formation) and Citronelle Formation	Increasing ground-water withdrawals and resulting water level declines resulted in lateral intrusion from Gulf and and the Pascagoula River estuary at Moss Point	None; monitoring program established
Biloxi area	Miocene	A few localities have had chloride increases	None
North Carolina			
Southeastern	Castle Hayne and Paleocene (Beaufort)	Large scale pumping to dewater aquifer for mining operations resulted in the movement of brackish water into zones of the aquifer both laterally and vertically	Area was declared a capacity use area for water management

Table 61. (cont) SUMMARY OF CASE HISTORIES ON SALT-WATER INTRUSION[17,55,127,178-213]

Location	Aquifer	Nature of Problem	Remedial Action
South Carolina			
Beaufort and Charleston areas	Santee and Ocala Limestones and Peedee-Black Creek Sands	Heavy pumping caused upward and downward intrusion from layered saline aquifer and lateral intrusion from coast	Many wells abandoned; some water supplies imported
Virginia			
Newport News and Cape Charles areas	Cretaceous	Sea-water intrusion or residual saline water contaminated wells	Designated as critical ground-water areas

based on a review of 40 individual county and regional ground-water resource reports and an Environmental Protection Agency report entitled "Salt Water Intrusion in the United States."

Within some sections of the Southeast, one of the most common problems related to abandoned or improperly cased water wells as a source of contamination is the vertical movement of saline water into a fresh-water aquifer. Thousands of wells have penetrated artesian aquifers that either flow or have sufficient hydraulic head to cause upward leakage into overlying aquifers through corroded casings or around improperly cased or grouted wells. Improperly cased or corroded wells drilled near the sea, salt-water marshes, or tidal streams have, in several instances, permitted salt water to leak downward into a fresh-water aquifer. Over a period of time, this salty water can migrate significant lateral distances.

In the study area, numerous state ground-water evaluation reports discuss the problem of uncontrolled flow from and within abandoned water wells. In Florida, during the period from 1955 to 1959, the State Geological Survey conducted an inventory of flowing wells. Information was collected on over 4,000 wells located in 45 counties, and 1,200 of these were found to have uncontrolled continuous flow. The chloride content of the water from approximately 50 percent of the flowing wells exceeded the recommended limit of 250 mg/l.214) At the present time in southwest Florida alone, there are an estimated 2,000 to 3,000 wells that flow poor quality water. About 100 of these wells have been located and marked for inclusion in a water-quality improvement project.215)

In 1958, an inventory was made of wells and water use in the 10 coastal counties of Georgia. In seven of the counties, 377 flowing wells were found; wells no longer flow in one county, and very few, if any, flow in the remaining two counties.216) Much of the uncontrolled flow from wells serves no useful purpose.

At La Belle, Florida, upward leakage through five deep artesian wells that were not in use and lateral movement through a subsurface water-distribution system which acted as a conduit were the probable sources of contamination of the shallow aquifer over a broad area. Most of the supply wells in La Belle range in depth from 18.3 to 36.6 m (60 to 120 ft) and are completed in a limestone horizon. The deep wells were cased in the limestone to a depth of about 24.4 m (80 ft) and completed with an open bore to depths of 183 to

244 m (690 to 800 ft). Thus, a direct connection existed between the open bore of the deep wells and the zone tapped by the shallow wells. The potentiometric surface in the deep wells was approximately 7.6 m (25 ft) above land surface, and the water level in the shallow wells was below land surface. Figure 51 shows the distribution of chlorides in the shallow aquifer.[217,218]

At Highland Estates, Florida, several residents reported that water from their shallow domestic-supply wells tasted salty. The wells ranged from 6.1 to 7.6 m (20 to 25 ft) deep in the water-table aquifer, except for one abandoned irrigation well nearby which tapped the deep artesian aquifer. Shown on Figure 52 are the locations of these wells and the chloride concentrations in water samples collected from them. Chloride concentrations in water from the shallow wells ranged from 20 mg/l for Well 3, located outside the contaminated area, to 590 mg/l from Well 2, situated in the contaminated area. The chloride content of water from the deep well was 1,800 mg/l. The potentiometric surface in this well was approximately 5.8 m (19 ft) above land surface. A control valve was installed to prevent flow from the well, but the metal well casing was badly corroded and leaking. The well was plugged with a cement grout which stopped all visible leakage and, following this action, the chlorides in the water from the shallow wells decreased as shown on Figure 53.[219]

In Greene County, Alabama, the Gordo and McShan Formations, which consist chiefly of sands and clays, are two of six geologic formations used as aquifers. The chloride concentration in water from the Gordo Formation ranges from 4 to 3,700 mg/l, while the chloride concentration in water from the McShan Formation ranges from 3.8 to 2,560 mg/l. Many of the wells tapping these formations flowed at land surface and yielded water with a chloride concentration that exceeded the recommended limit of 250 mg/l.[220]

In several instances, improperly installed or corroded well casings in wells drilled near tidal streams or salt-water marshes permitted salt water to leak downward into a fresh-water aquifer in the Savannah, Georgia, area.[221] Another case of contamination of the fresh water aquifer occurred near Brunswick, Georgia; salt water under higher hydraulic head leaked upward through an improperly cased exploratory oil well. (This case history is discussed in more detail in the chapter dealing with petroleum exploration and development.)

In North Carolina, ground water from a private well was contaminated. The well was located at the lowest point on

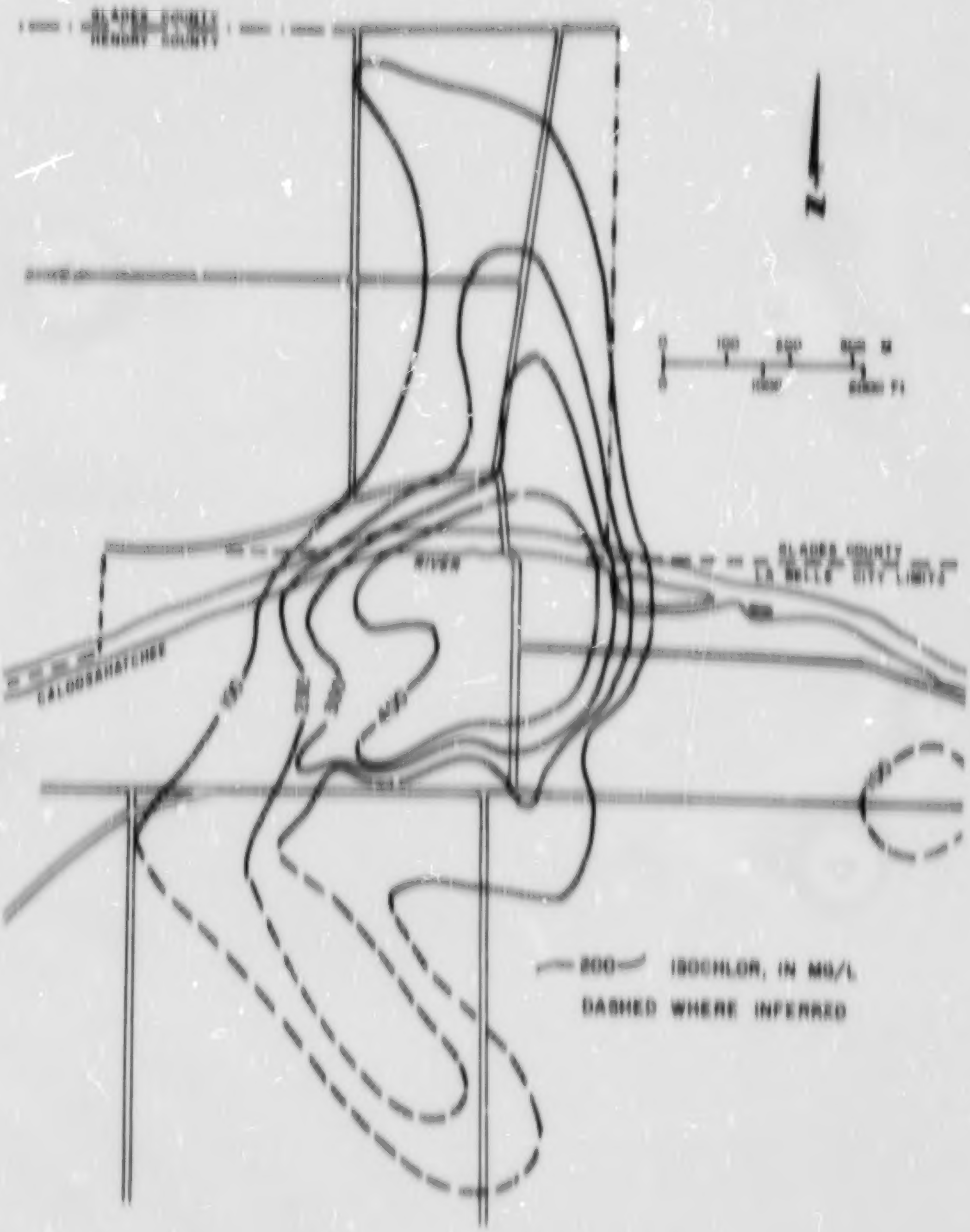

GLADES COUNTY
HENDRY COUNTY
N
0 100 200 300 M
0 1000 2000 FT
RIVER
CALOOSAHATCHEE
GLADES COUNTY
LA BELLE CITY LIMITS
200 ISOCHLOR, IN MG/L
DASHED WHERE INFERRED

Figure 51. Distribution of chlorides in the shallow aquifer at La Belle, Florida, 1952-1953,217,218)

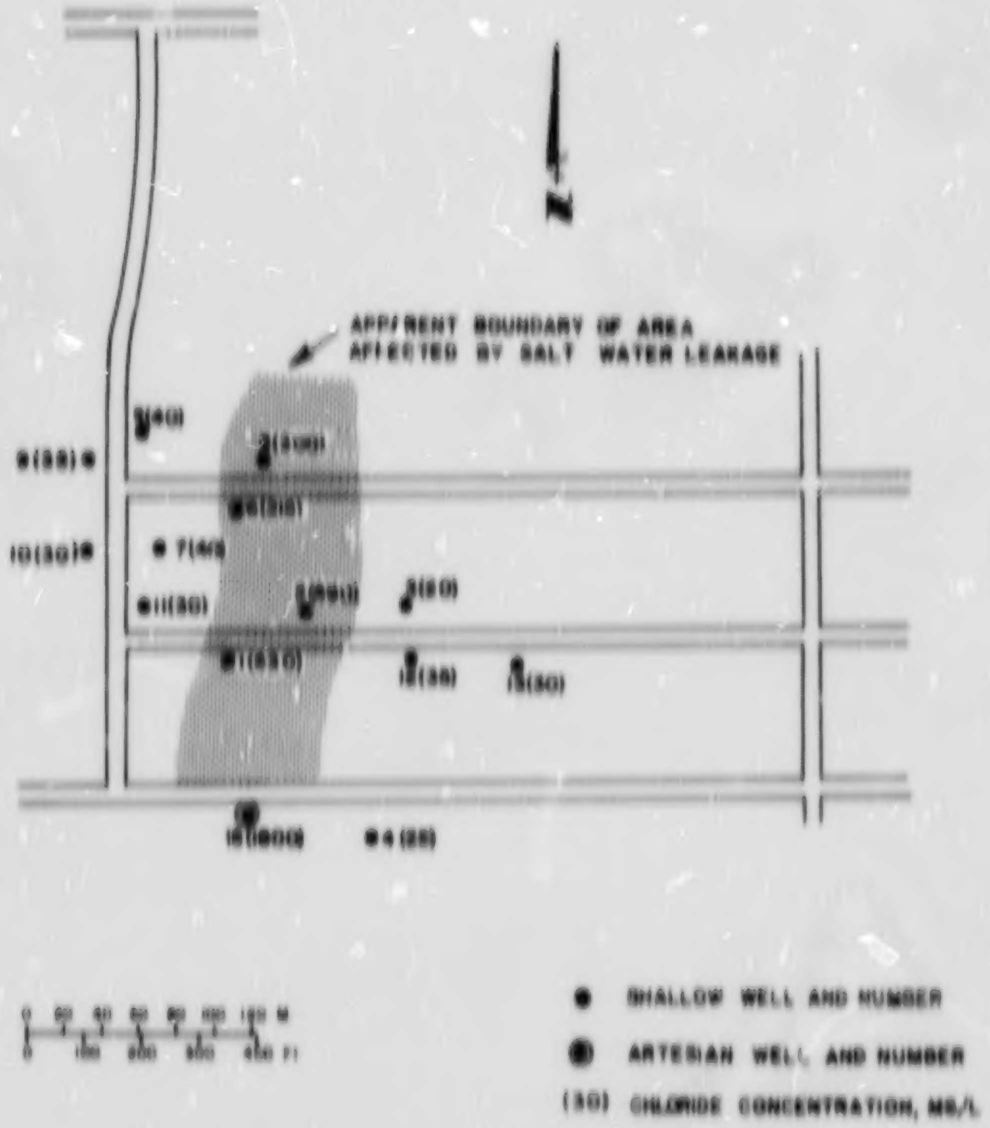

N
APPARENT BOUNDARY OF AREA AFFECTED BY SALT WATER LEAKAGE
10(30)
7(40)
11(30)
4(25)
0 20 40 60 80 100 120 M
0 100 200 300 400 Ft
SHALLOW WELL AND NUMBER
ARTESIAN WELL AND NUMBER
(30) CHLORIDE CONCENTRATION, MG/L

Figure 52. Chloride concentrations of water in wells at Highland Estates, Florida.219)

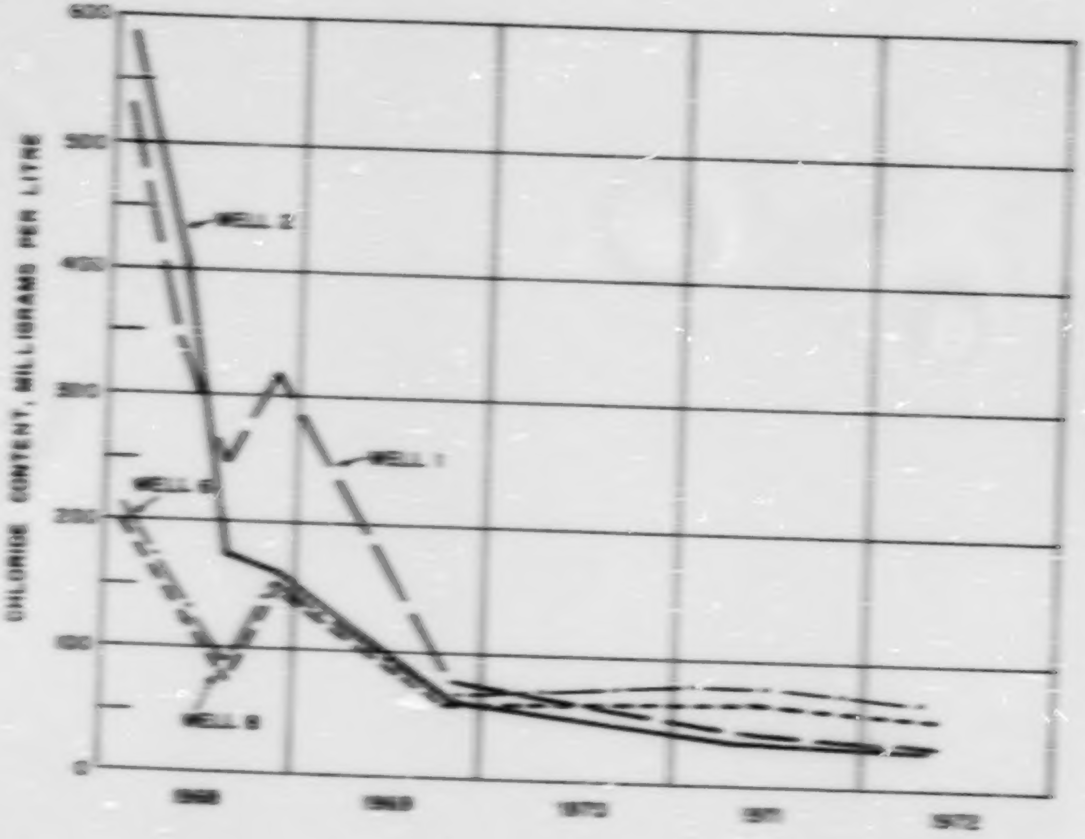


Figure 53. Decline of chloride concentration in water samples from wells at Highland Estates, Florida, after plugging leaky artesian wells.2(9)

the property, approximately 6.1 m (20 ft) from a ditch that received domestic waste water, and it did not have a sanitary seal at land surface. A bacteriological sample of water from the well showed the well to be contaminated by fecal coliform.[57]

In Colbert County, Alabama, a large number of wells are contaminated with bacteria which cause the precipitation of iron hydroxide. The problem is most acute in water wells that do not have surface casings extending above land surface.[232]

Future Trends

The use of ground water as a source of supply will continue to increase in the future. Ground-water development imposes a physical change on the hydrogeologic environment by drawing down water levels; this results in either physical, chemical, or biological reaction within the system. Large ground-water developments, for industries or communities, should require the preparation of an environmental impact statement. However, because of cost, little can be done to control environmental impacts by domestic wells, except through greater participation of state ground-water geologists. Such participation may allow problems to be avoided prior to the actual development.

Because of the close regulatory control over diversion of ground water in coastal regions and because of the general knowledge of the location of saline ground-water bodies, it is unlikely that the number of problems of contamination from this source will rise significantly. However, a change in water-management attitudes might lead to the establishment of new inland positions of salt-water fronts in some areas. These changes might occur in response to greater demands for water supply in coastal areas because of continuing population growth.

Some of the counties within the Atlantic and Gulf Coastal Plains may become water-short in the near future, and a decision will have to be made on how to best meet increasing water needs. One possibility is the importation of surface water into those areas presently dependent upon ground water. Another alternative would involve abandonment of the present management concept of maintaining salt-water fronts in a status-quo position and withdrawing more fresh ground water for consumptive use; salt water would then move inland to a new position. The cost of replacement of wells lost in the process might be much less than the cost of importing surface water or the cost involved with some other alternative proposed for solving water-supply needs. A technical-economic evaluation of the feasibility of withdrawing more ground water in coastal areas would be a valuable aid to water managers.

More controls are needed over the construction of domestic wells and the fate of abandoned wells. Stricter licensing of well drillers in areas where regulations do not exist would help to correct some of the faulty construction practices now being used. Also, the arbitrary reasoning behind some rules involving such protective codes as distances to potential sources of contamination should be reevaluated. Some of these codes have been in existence for many decades, and the occurrence and movement of ground water under various hydrologic and geologic conditions was not adequately understood at the time of their implementation.

PETROLEUM EXPLORATION AND DEVELOPMENT

Exploration for petroleum has taken place in each of the states in the study area. The principal producing areas are found in Mississippi and Alabama, with some minor production in Florida and Virginia. Georgia, North Carolina, and South Carolina are non-producing states.223) Development of many oil fields took place during the first half of this century. Most production occurred during initial development which was followed by a period of declining yields. At present, many of the wells in these fields produce little oil and gas, and much brine.

The large volumes of brine from these wells represent the principal threat to water quality in fresh-water aquifers in a petroleum recovery region. The natural brine from deep strata is brought to the surface with the petroleum product and is then separated from it. The brine waste is disposed of in surface-water bodies, in unlined settling pits, in injection wells for secondary recovery or disposal, or it is pumped into the annulus between the production casing and the surface casing. Pipelines and separation tanks may be in a state of disrepair at these installations, and fluids might therefore discharge onto the land surface, infiltrate shallow fresh-water aquifers and cause contamination.

Brines flowing from and within abandoned oil and gas wells can contaminate fresh-water aquifers. Even when an oil company conscientiously applies a program of capping and/or plugging abandoned wells, casings may eventually corrode and leak, thus introducing brine or a brine-oil-gas mixture into a usable aquifer.

The chemical characteristics of brine are quite variable. Oil field brines can be many times more saline than sea water (Table 63) and they are highly corrosive to metals. Only small quantities of brine can cause severe degradation of fresh-water aquifers.

Most of the current oil and gas exploration and development in the region is centered on the Gulf Coastal Plain. This broad lowland plain is underlain by aquifer systems that are extensively developed as primary sources of domestic, municipal, and industrial water supplies. A non-degradable pollutant, such as brine, disposed of on the land surface, injected into annular spaces, or escaping through the well itself, can eventually migrate to water-supply pumping centers or natural discharge areas. The result can be regional ground-water contamination.

Case Histories

The total number of cases in which water wells in the Southeast have been contaminated as a result of petroleum exploration and development is not known. Individual cases and regional effects have been noted, but the overall problem has not been studied in detail.

In Alabama, there are 19 oil fields with approximately 556 producing wells. About 1,000 exploratory wells have been drilled outside the producing areas.[225] Ground-water contamination from brine has occurred in the Pollard, Gilbertown, Citronelle, and South Carlton Oil Fields.[226] The three principal sources of contamination are unlined disposal pits, leaks from pipelines, and spills. A problem also originated from the improper design of a brine disposal well.

The Pollard Oil Field encompasses 178 ha (440 acres); it is estimated that 162 ha (400 acres) are affected by brine contamination. The shallow aquifer in the area is composed of about 15 m (50 ft) of sand and gravel and is a source of water for domestic and stock supplies. It is underlain by relatively thick beds of clay which have prevented the downward movement of contaminated water to deeper aquifers used as supply sources for the town of Pollard. The primary method of brine disposal at the oil field is through wells. However, there were 28 pits used for secondary disposal. Field investigations have proven that the use of surface pits was a major factor contributing to the contamination of the shallow aquifer. From 1955 to 1962 the area of contamination enlarged considerably (Figure 54). During this period, one local resident relocated a domestic and stock

Table 63. COMPARISON OF DISSOLVED SOLIDS IN SEA WATER AND IN OIL FIELD BRINE, in mg/l. 224)

Element	Sea water, mg/l	Oil field brine, mg/l
Sodium	10,600	12,000 to 150,000
Potassium	380	30 to 4,000
Lithium	0.2	1 to 50
Rubidium	0.12	0.1 to 7
Cesium	0.0005	0.01 to 3
Calcium	400	1,000 to 120,000
Magnesium	1,300	500 to 25,000
Strontium	8	5 to 5,000
Barium	0.03	0 to 1,000
Chloride	19,000	20,000 to 250,000
Bromine	65	50 to 5,000
Iodine	0.05	1 to 300

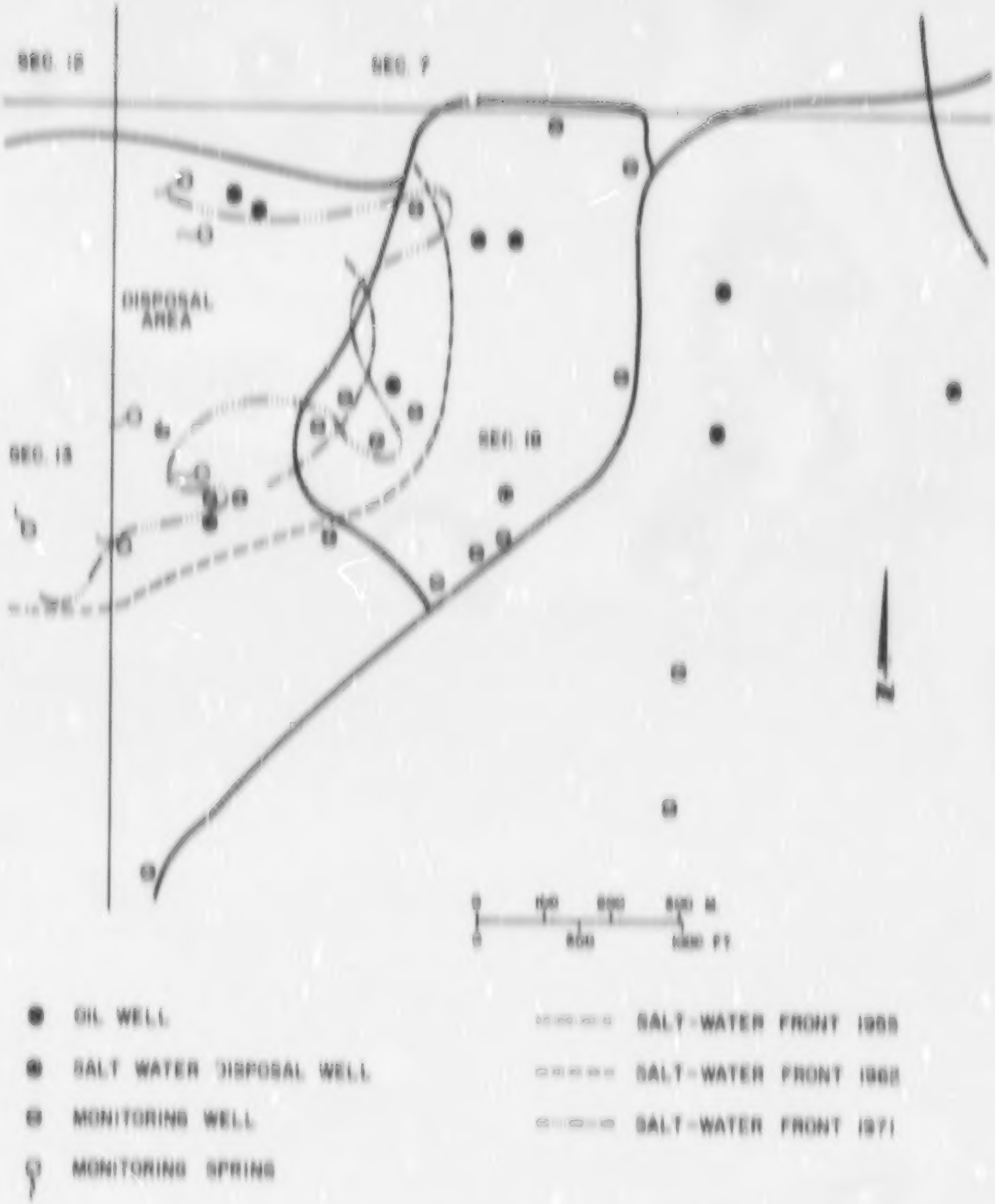

SEC. 12
SEC. 7
DISPOSAL AREA
SEC. 13
SEC. 18
N
0 150 300 450 M
0 500 1000 FT
OIL WELL
SALT WATER DISPOSAL WELL
MONITORING WELL
MONITORING SPRING
SALT-WATER FRONT 1955
SALT-WATER FRONT 1962
SALT-WATER FRONT 1971

Figure 54. Salt-water contaminant fronts in part of the Pollard Oil Field, Alabama.276,227)

supply well three times because of high chloride content in the water. In September, 1963, the State Oil and Gas Board requested that the use of surface pits for the disposal of brines be discontinued. Compliance with this request caused the chloride concentrations in the shallow aquifer to decrease, and the contaminant front began to recede (Figures 54 and 55). Numerous pipeline leaks and spills have also occurred at the field. The effects of these incidents were observed in nearby monitoring wells (Figure 55). Saline water seeps and tree kills have also been observed in the area contaminated by the brine.226,227,228)

At the Gilbertown Oil Field, a review of the construction of one brine disposal well revealed that it was discharging brine into an aquifer that contained good-quality water. In addition, brine was disposed of in 21 pits. The storage capacities and the construction of these pits were not adequate for the quantity of brine they received. The dikes around many pits were low; overflows commonly occurred during rainstorms. Evidence of contamination was observed as tree kills and in gaining streams that had poor-quality water. In 1971, the State Oil and Gas Board issued an order discontinuing surface disposal.226,227)

At the Citronelle Oil Field, waste water had been disposed of through five wells and two pits. Apparently, no problems have been encountered with the disposal wells. However, one of the pits was losing water through seepage and the effect was an increase in chloride concentration in a stream approximately 457 m (1,500 ft) away.226,227)

In Mississippi, at the beginning of 1971, there were approximately 386 oil and gas production pools. Total brine production in the state up to January of 1971 amounted to 2,608,191 cu m (16,406,813 bbl).229) Some brine disposal was formerly accomplished by discharging into both pits and disposal wells. In 1973, the use of pits was phased out, except on an emergency basis.230)

Disposal wells utilized are of two types: (1) a well drilled as a disposal well or converted from an oil or gas well, and (2) a well in which brine is disposed of through the annulus of a producing oil or gas well. At the end of 1971, there were approximately 395 disposal wells located in 25 Mississippi counties. In 13 of the 25 counties, ground-water contamination problems from oil field brines have been reported. Injection wells used for secondary recovery were not included in the total number of disposal wells.229)

Several oil fields have disposal wells that are injecting through the annulus between the surface casing and the inner

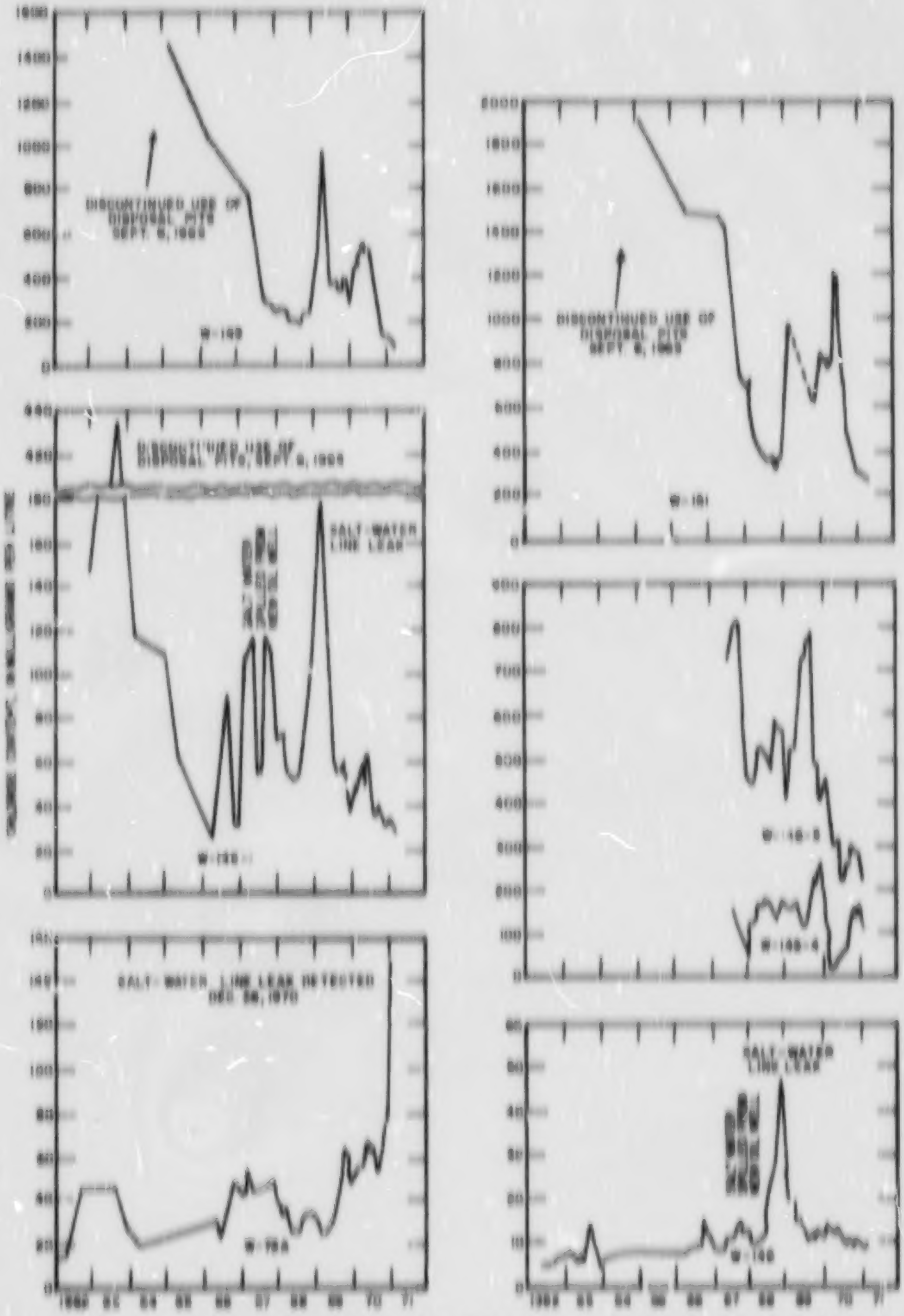


Figure 55. Chloride concentration in water from monitoring wells at Pollard Oil Field.227)

or production casing. Fresh-water aquifers may not be adequately protected around wells that inject through the annulus, and sometimes records of wells do not exist so that this determination can be made. The drilling of deep water-supply wells revealed instances of apparent associated pollution.229,231) In southeastern Mississippi, two 549 m (1,800 ft) deep water supply wells which originally produced low-chloride water presently produce water with chlorides of 45 to 50 mg/l and 225 to 250 mg/l, respectively. These supply wells are located approximately 1.6 km (1 mi) and 4 km (2.5 mi) from a brine disposal well injecting through the annulus.232) Several other cases of contamination supply wells located near oil fields have been reported. The extent of contamination of fresh-water aquifers by improper or careless disposal well practices has not been determined.

In Wayne, Wilkinson, and Yazoo Counties, Mississippi, saline seeps and brine springs have been reported in areas where there is oil production. The seeps and springs have resulted from the use of unlined disposal pits.61,233,234)

An abandoned, unplugged oil test well in Glynn County, Georgia, contaminated a fresh-water aquifer. The test well was drilled to 1,407 m (4,615 ft) through both fresh- and salt-water aquifers. The deepest casing setting was 186 m (610 ft) and the well was completed open-bore to 1,407 m (4,615 ft). A well survey showed that salt water was flowing upward from aquifers deeper than 610 m (2,000 ft) into a fresh-water aquifer between 186 and 280 m (610 and 920 ft). Water from the well contained a maximum chloride concentration of 7,780 mg/l. Two nearby water-supply wells showed a slight increase in chloride content, indicating a lateral movement of the salt water.235)

Future Trends

In the region, oil and gas producing states have developed controls to insure that minimal adverse environmental effects from this source will occur in the future. For example, the State Oil and Gas Boards of Mississippi and Alabama, are responsible for oil and gas development and for the regulation of brine disposal. However, these dual functions of promoting development and of regulating disposal practice could present problems. Appropriate state water-quality control agencies might become involved in disposal methods only after brines had been processed in some manner and had thus fallen in the category of industrial wastes. From an environmental standpoint, an independent organization might control disposal activities more appropriately.

Much work still remains to be done, especially in delineating more exactly the extent and magnitude of contamination in polluted areas. For the most part, existing contamination passes unnoticed because it usually occurs in sparsely populated areas. However, as urban and suburban development proceed, reports of contamination from past petroleum exploration and development will probably increase. Also, the corrosion of casings and the failure of seals in abandoned oil and gas wells will continue to be a problem. These problems may be partially offset by a growing effort on the part of public agencies to have abandoned wells properly plugged. However, little can be done about wells abandoned before plugging regulations were adopted.

NATURAL BODIES OF SURFACE WATER

Throughout the Southeast, rivers and lakes may be a major source of recharge to properly positioned public and industrial well fields or may supply a large amount of water to the aquifer. Where a surface-water body is hydraulically connected with an aquifer, pumping from wells and the resulting drawdown of water levels in the aquifer can induce surface water to infiltrate through the stream or lake bed and into the ground-water reservoir. This infiltrated water can then migrate to the pumping wells. Studies have shown that wells drilled within a few hundred to as many as a thousand feet away from rivers and lakes can yield a high percentage of water derived by induced infiltration.

If the infiltrated water passes through a large enough volume of soil and aquifer material before arriving at the pumping well, filtration, adsorption, and ion exchange can take place. Turbidity, bacteria, and some chemical constituents can be effectively removed or reduced. Thus, usable ground-water supplies can sometimes be developed adjacent to poor-quality streams. This fact plus the large amount of potential recharge available from major streams has made the siting of wells adjacent to surface-water bodies attractive to water-works operators.

Unfortunately, few investigations have been made to determine how far pollutants such as heavy metals, organic compounds and viruses can migrate through aquifer materials to pumped wells. Bacteria have been known to survive infiltration from the surface-water source to the well. Also, acid or reducing surface waters that come in contact with some aquifer materials can dissolve minerals such as iron and manganese which naturally occur in the sediments. This has resulted in an increase in concentration of some chemical constituents in the well water and necessitated the construction of treatment facilities for their reduction. In some instances, the chemical concentrations have been great enough to result in abandonment of the well supply.

The possibility of contamination of ground-water resources is greatest under conditions where contaminants enter a stream with low flow or where they are contained in surface waters forming a large part of the flow into a closed lake. Throughout the Southeast, and particularly in Florida, various-sized lakes near centers of population may be receiving treated municipal sewage waters and urban storm runoff. Little is known of the natural capacity of lake bottom sediments to retain some of the materials in storm runoff. Adsorption on these sediments or metal-sulfide processes occur on lake bottoms, and therefore trace metals may remain in the lake system rather than enter the aquifer. Since this subject has not been studied in great detail, the possibility of infiltration of such substances must not be discounted. Additionally, well fields located near such lakes may induce flow from them sufficient enough to change the geochemical conditions under which the contaminants remain stable in the bottom sediments of the lake.

Another factor favoring contamination of ground-water resources in the southeast states is the occurrence of lakes and streams in areas underlain by cavernous carbonate rocks. Many of these bodies of water, which would otherwise be hydraulically connected to those rocks, have bottoms plugged with silt, clay and organic matter. On occasions, the bottoms of these water bodies collapse and a mixture of sediments and water will move down into the cavernous openings. If the sediments and waters contain contaminants, the aquifer becomes locally contaminated. Movement of contaminants can be quite rapid once they have entered the cavernous zones due to natural regional flow or due to flow induced by nearby pumping.

In Leon County, Florida the location of a number of large lakes is controlled by the presence of active sinkhole structures. Two of the lakes, Lake Iamonia and Lake Jackson, are hydraulically connected with the underlying Floridan Aquifer. Occasionally, organic debris and clay acting as a plug in sinkholes in the bottoms of the lakes will come loose and the lake waters will drain out.[45] This occurs when heavy rains follow drought conditions. The lake levels rise and there is a big head difference between those levels and the lowered piezometric surface of the underlying aquifer. Three other lakes in the area, Lafayette, Miccosukee and Bradford, are either underlain by sinkholes, flow out into sinkholes during wet weather, or lose water to sinkholes in the streams feeding the lake.

Over two-thirds of Leon County has pronounced sinkhole development, particularly south of Tallahassee, where Lake Munson is located. Urban storm runoff from approximately 65 percent of the 67 sq km (26 sq mi) area of Tallahassee, drains into Lake Munson. Twenty percent of the area drains into Lake Lafayette and the balance into Lake Jackson.[236] Additionally, 37,841 cu m/d (10 mgd) of treated municipal sewage from Tallahassee drain into the lake. As much as 563,830 cu m (149 million gal) of storm runoff will enter the lake as a result of a storm event.[237] From both a biological and chemical viewpoint, the 107-ha (264-acre) lake is polluted. Except for solid wastes, the particulate and dissolved wastes of 120,000 people are entering the lake and are stored there.

A study of road surface runoff indicates that runoff from the first hour of a moderate-to-heavy storm with brief peaks to at least 12.7 mm (1/2 in) per hour would contribute considerably more pollutional load than would the same city's sanitary sewage during the same period of time (Table 64).[238] The data presented in Table 64 are for a city of comparable size and population to Tallahassee, Florida.

This same study determined the quantity and character of contaminants found on street surfaces in 12 U. S. cities (Table 65). It points out that the greatest pollution potential is associated with the fine solids fraction of the street surface contaminants, noting that current street-cleaning practices are essentially for aesthetic purposes. Cleaning efficiency in the removal of the dust and dirt fraction of street surface contaminants is low even under well operated street-sweeping programs. Also, catch basins are ineffective in removing the fine solids which contribute most heavily to water pollution.[238]

In central Florida, a recharge area for the productive Floridan Aquifer, lakes are abundant. Some of these lakes are relatively independent of the effect of artesian pressures due to the presence of underlying sediments which restrict the upward or downward movement of water. Other lakes are connected directly to the underlying artesian Floridan Aquifer and lake levels fluctuate directly with changes in the piezometric surface, except during periods of surface flow.[239] Contaminants entering the lakes have the potential of downward movement into the artesian aquifer, given sufficient head differences which may result in lake bottom collapse or direct movement of contaminants into the

Table 64. CALCULATED QUANTITIES OF POLLUTANTS WHICH WOULD ENTER RECEIVING WATERS (HYPOTHETICAL CITY)a) 238)

	Street Surface Runoff lb/hr	Street Surface Runoff kg/hr	Raw Sanitary Sewage lb/hr	Raw Sanitary Sewage kg/hr	Secondary Plant Effluent lb/hr	Secondary Plant Effluent kg/hr
Settleable plus suspended solids	560,000	254,000	1,300	590	130	59.0
BOD_5	5,600	2,540	1,100	499	110	49.9
COD	13,000	5,897	1,200	544	120	54.4
Kjeldahl nitrogen	880	399	210	95	20	9.07
Phosphates	440	200	50	22.7	2.5	1.13
Total coliform bacteria (org/hr)	$4,000 \times 10^{10}$		$460,000 \times 10^{10}$		4.6×10^{10}	

a) The hypothetical city used for this comparison had the following characteristics:

Population: 100,000 persons
Total land area: 5,666 ha (14,000 acres)
Distribution of developed land residential: 75%,
commercial, 5%, industrial 20%
Streets (tributary to receiving waters): 644 curb km (400 curb miles)
Sanitary sewage: 45.4×10^6 l/day

Table 65. QUANTITY AND CHARACTER OF CONTAMINANTS FOUND ON STREET SURFACES.(238) (12 U. S. Cities and Towns)

Measured Constituents	Weighted Mean for All Samples kg/curb km	Weighted Mean for All Samples lb/curb mi
Total solids	395	1,400
Oxygen demand		
BOD_5	3.8	13.5
COD	26.8	95
Volatile solids	28.2	100
Algal nutrients		
Phosphates	0.31	1.1
Nitrates	0.026	0.094
Kjeldahl nitrogen	0.62	2.2
Bacteriological		
Total coliforms (org/curb km and mi)	27.9×10^9	99×10^9
Fecal coliforms (org/curb km and mi)	1.58×10^9	5.6×10^9
Heavy metals		
Zinc	0.18	0.65
Copper	0.06	0.20
Lead	0.16	0.57
Nickel	0.014	0.05
Mercury	0.02	0.073
Chromium	0.03	0.11
Pesticides		
p, p-DDD	18.9×10^{-6}	67×10^{-6}
p, p-DDT	17.2×10^{-6}	61×10^{-6}
Dieldrin	6.8×10^{-6}	24×10^{-6}
Polychlorinated biphenyls	310×10^{-6}	1100×10^{-6}

NOTE: "org" refers to the number of coliform organisms observed.

aquifer due to recharge from the lakes. Fertilizers and pesticides carried by surface and subsurface water draining into the lakes are an increasing source of contamination.239)

Lake Dicie, in Lake County in central Florida, receives urban storm runoff from the southeastern part of the town of Eustis. This inflow accounts for almost 50 percent of the total input which includes rainfall on the lake and other storm runoff. Outflow from the lake consists primarily of seepage and evaporation, with seepage almost twice the evaporation. This seepage is probably outward through the shallow aquifer as well as downward into the Floridan Aquifer.240)

Most of the trace elements entering Lake Dicie do not remain in solution but are adsorbed on particulate matter. Concentrations of phosphorous, nitrogen, lead and trace elements are higher in the bottom sediments than in the water. Lead concentrations in the runoff were 56 µg/l and only one µg/l in the lake waters.240)

In the area of Florida where Lake Dicie is located, old sinkholes and depressions, some of which are present-day lakes, contain Miocene or more recent sand and sandy clay to considerable depth.239) A well near Orlando has penetrated a 27.4 m (90 ft) deep cavern at a depth of between 175 to 202 m (573 to 663 ft) below land surface, containing 3.7 m (12 ft) of black organic muck.241) This is an indication that surface materials do move downward into the Floridan Aquifer. The entire region is pock-marked by sinkholes and related features and underlain by extensive interconnected cavernous limestone. The potential impact of infiltration of contaminants through sinkhole lakes on local ground-water quality is increased even more by practices such as those occurring at Lake Dicie.

The purpose of the foregoing discussion is to point out poor practices which can potentially cause ground-water contamination. Similar conditions and practices exist in other areas of the Southeast. The following case histories illustrate problems that have occurred as a result of infiltration of contaminants from bodies of surface water or by introduction of contaminants through sinkholes underlying them.

Case Histories

A sinkhole opened up in the bottom of Lake Grady in Hillsborough County, Florida, and drained lake water into the underlying aquifer. Approximately 12 domestic supply wells in a neighborhood east of the lake were bacterially contaminated and contained foreign matter similar to that found in the lake. The sinkhole was to be filled in and sealed with a clay barrier to prevent further seepage.242)

There are indications that surface water draining into sinkholes located in the Masaryktown Canal in Hernando County, Florida, during a period of great precipitation (approximately 610 mm or 24 in during June, 1974) contaminated a nearby well with coliform bacteria. An investigation and subsequent tests by the Southwest Florida Water Management District using rhodamine dye were not conclusive. However, water does move from the canal into the sinks and contamination during the period was possible.243)

At Lake City, Florida, the municipal sewer system emptied into a small creek that flowed into a sinkhole lake. Polluted lake water drained through open sinkholes in the lake bottom into the Floridan Aquifer, contaminating the city well field located at the edge of the lake. The city well field was moved upgradient from the source of contamination and a sewage-treatment plant has been built.244)

Sewage effluent from a treatment plant in Dublin, Virginia, discharged into a dry ditch and entered the ground-water regime at a point approximately 229 m (750 ft) downstream through a series of solution cavities. From this point, the contaminant flowed along the axis of a syncline. The majority of the contaminated water rose to the surface some 5 km (3.1 mi) from the point of entry. However, several wells and springs used for water supply were affected. The water-supply problem was resolved by extending the public system to supply the citizens affected by the discharge.245)

A rather rare form of contamination occurred at Donalsonville, Georgia, where primary effluent from a sewage treatment plant entered a stream and flowed into a hole formed by a piling that was driven into a previously undisclosed cavern. The pilings were being driven for the construction of a bridge crossing the stream. Bacterial contamination appeared in 31 of 126 wells sampled which tap the principal artesian aquifer of Georgia.246)

At Baconton, Georgia, a stream serving as an open sewer contaminated the principal artesian aquifer. The discharge flowed into a limestone sinkhole. Bacterial contamination was found in nearby wells.61)

At a site along Town Creek in Athens, Alabama, there is considerable stream pollution due to direct flow of waters from septic tanks and sewage dumped into the creek. This contamination is drawn into the cone of depression of one of the town wells where a bacteria count of 2,925 per cubic centimeter was observed. Nitrate in this well was only 4 mg/l, which might be explained by the fact that nitrification processes had not taken place and that the nitrogen compounds remained in the less oxidized forms.[247]

Future Trends

Cases similar to those described above are very common throughout the Southeast. However, in spite of the cost for treatment brought about by this type of problem, the development of ground water as compared to surface water is still economically favorable. The drilling of wells recharged by rivers and lakes will continue, and infiltrated ground water will remain as a vital source of supply for municipalities and industries.

Unfortunately, few detailed chemical analyses are available for water from wells which depend on a high percentage of recharge from polluted bodies of surface water. More information is needed on the fate of such trace substances as heavy metals and organic compounds in waters that are infiltrated from rivers and lakes. Pesticides, for example, can concentrate in bottom sediments of surface-water bodies, and data are lacking on whether these substances can be leached by surface waters induced into underlying aquifers. In addition, many of these ground-water supply systems have been in operation for many years. Conceivably, the ion exchange and adsorptive capacities of the aquifer sediments for removal of potential pollutants may be nearly exhausted. Information is lacking on the ability of various types of sediments to treat infiltrated surface water and the time factors involved.

Health agencies in the region generally rely on maintaining an arbitrary distance between the well supply and the surface-water source as a safeguard against ground-water contamination. Also, codes covering well construction call for sealing the well against possible leakage of surface water along the annular space outside the casing and require the site to be protected against flooding from the nearby stream. Pumping tests of up to five days are another requirement, the purpose of which, theoretically, is to provide enough data for determination of the effects of infiltrated surface water on ground-water quality.

Because of the highly complex geologic and hydrologic conditions that occur in the study area, especially in the carbonate-rock portion, these safeguards may not be adequate. The ability for surface water to infiltrate to high-capacity wells varies greatly from place to place. For example, a uniform distance of 61 m (200 ft) for wells located near two polluted streams of similar quality may be safe in one instance but not in the other, depending on the percentage of surface water infiltrated, the time of travel for a drop of water to migrate from the bottom of the stream bed to the well screen, and the ability of the sediments in the aquifer to modify the quality of the surface water. Weeks, and in some cases months, of pumping may be required for a detectable volume of infiltrated surface water to reach a particular well. Only then can a proper judgment be made on long-term water-quality relationships between surface water and ground water.

Regulation of well development adjacent to streams should be based on a more specific and technical analysis of hydraulic and water-quality conditions at each particular site under consideration. In some cases, ground-water supplies that may be perfectly safe for public consumption are not being developed because they do not meet arbitrary location requirements set by regulatory agencies. At other sites, the parameters are being met but may not be protective enough.

HIGHWAY DEICING SALT

During the winter, highway departments in the northern part of the southeast study area apply salts (sodium chloride and calcium chloride) to roads to control or eliminate ice and snow. In many states of the northeast, problems caused by this practice have showed up, and there is an increasing concern about the resulting environmental dangers posed to vegetation, soil, and water supplies. Deicing salts contaminate surface runoff, ponds, streams, and ground water, principally near roadside areas. Substances added to deicing salts to prevent caking or to inhibit corrosion, such as sodium ferrocyanide and phosphorous compounds, can be extremely toxic to human, animal, and fish life.

No more effective, economical, and easily handled substances for maintaining a dry pavement have been found than salts, and particularly sodium chloride. Because of the relatively low cost, excessive application frequently occurs. However, only three of the seven southeastern states reportedly use highway deicing salt on a regular basis. During the winter of 1973-74 Virginia used 56,940 tonnes (62,723 tons), North Carolina 16,413 tonnes (18,080 tons), and South Carolina 45.4 tonnes (50 tons).

Runoff from road surfaces eventually finds its way into streams and rivers within the drainage basin occupied by the highway or percolates into the soils adjacent to the highway. The sodium, calcium, and chloride ions in the soil can be carried down to the water table by the runoff water itself or, during periods of recharge, by rainfall. Contaminated water can then move through the saturated zone until it is discharged into a surface-water body, is leaked into an adjacent aquifer, or is pumped from a well. Although sodium and chloride ions can both move through the unsaturated and saturated zones, sodium is chemically more attracted to a wider variety of soil types. This characteristic accounts for the relatively higher ratio of chloride to sodium encountered in contaminated ground water than is normally found in surface waters receiving direct runoff of salt-laden waters.

Another source of ground-water contamination related to salts used for highway deicing is the storage of this material in piles at central distribution points. There are numerous storage sites throughout the northern part of the study region and, in autumn, each holds from several hundred to several thousand tonnes of salt. The nature of rock salt permits outside storage over relatively long periods of time without hard caking or noticeable loss in volume. Thus, many such salt piles are left uncovered on open land. This condition is especially common where the salt has been mixed with sand, resulting in a large volume of stored material that would require an expensive structure if the pile were to be sheltered.

Rain falling on the stockpile dissolves a portion of the salts and can carry them into the ground-water system. Typically, salt-spreading trucks are washed at storage areas, and infiltration of the resulting brine solution into the ground can aggravate the contamination problem. In some cases, drainage from salt piles and wash areas is collected and disposed of in dry wells. Thus, the pollutant is introduced directly into the geologic formation underlying the site.

After the pollutant has arrived at a domestic supply well or has moved into a municipal well field, an attempt generally is made to deepen the existing well, especially when the aquifer consists of consolidated rocks. Another procedure is to move farther away from the suspected source of contamination and construct a new well on the same property. Because chlorides are not considered toxic, casing off the affected aquifer zone and drilling deeper, or moving away from the source but tapping the same formation, are accepted as reasonable risks. However, even though initial chloride concentrations at greater depths or at new locations are low, the salty ground-water body is still present and may be within the influence of pumping of any new well. Ultimately, it too may have to be abandoned.

Case Histories

Although considerable amounts of highway deicing salts are applied in the states of North Carolina and Virginia, no evidence of contamination along roads was uncovered during the course of the study. However, it is most probable that such contamination is occurring.

In both North Carolina and Virginia, ground-water contamination by chlorides originating from highway salt stockpiles has occurred. Chloride levels rose to 1,520 mg/l in a well on the opposite side of a valley from a stockpile in Haywood County, North Carolina.[61] A well located in Goochland County, Virginia, contained 1,140 mg/l chloride as a result of seepage of dissolved salt from a stockpile.[248] In Dinwiddie County, Virginia, a well located 100 ft from a salt stockpile had chloride concentrations ranging from 484 to 1,400 mg/l.[249]

Future Trends

At the present time, there are no readily available, economical substitutes for salt as a snow- and ice-control substance. Therefore, it seems reasonable to assume that its use will continue in the northernmost states of the region, but probably not at the accelerated rate experienced in the past. However, if maximum benefits from its use are to be realized without causing excessive water pollution, control is needed in the areas of salt handling, spreading and application. Concerted efforts should be directed toward correcting wasteful and improper salt handling or application practices of major salt users such as highway maintenance departments.

One of the first steps taken should be to inspect existing and proposed salt storage sites to determine the pollution potential of each site and to devise means of pollution prevention or elimination if the inspections prove such actions to be necessary. As a general rule, uncovered salt storage piles should never be tolerated. Storage facilities should always include a water tight pad strong enough to support the weight of the salt and salt-handling equipment and a waterproof system of ditches and sumps at the edge of the storage pad to catch and hold for future use any brine outflow.

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SECTION VII

RESEARCH AND OTHER NEEDS

GROUND-WATER CONTAMINATION TRENDS

The ability to resolve ground-water contamination problems comes from an awareness of the sources of contamination resulting from man's past, present, and future activities. Many of these problems become more difficult to resolve because mode and range of human activities are considered for the present only. There is an awareness of today's activities because they are occurring now; there is less awareness of past activities because the minor events of man's existence are so poorly documented; there is a belief that some future activities can be anticipated.

Past activities do come back to haunt us: leachates from landfills constructed in the first half of the 20th century; nitrates and chlorides under old corrals and livery stables of the late 1800's;1) phenols from seepage related to gas-work plants operating in the early 1800's;2) and hydrogen sulfide from drainage of a seventeenth century Black Plague burial pit.3) Future contamination resulting from today's activities can be controlled by the foresight of today's individuals. Thorough records, particularly of disposal sites, need to be kept so that planners will be aware of past land use. Additionally, researchers should attempt to anticipate how future activities will cause ground-water quality problems.

In the past, the approach toward solving problems has been to apply corrective action after the contamination has been discovered. In the future, foresight and imagination should be used to locate and eliminate the potential causes of contamination.

The increasing incidence of ground-water contamination is in a large part controlled by a society which is both expanding in population and in demand for materials and services. The primary sources of contaminants will be those related to waste disposal activities (domestic, municipal, and industrial).

Population in the Southeast will grow faster than public sewerage can serve each new dwelling. The result will be more septic tanks, regardless of the potential for ground-water contamination.

The number of industrial and municipal landfills will increase, which today are under closer surveillance by state environmental and health departments. Proper engineering design should minimize leachate production from these sources and reduce contamination potential.

According to the Federal Water Pollution Control Act Amendment of 1972, discharge of toxic pollutants by industry will be controlled by effluent standards set by the Environmental Protection Agency, and industries must use the "best practicable" water-pollution control technology by July 1, 1977. The result has been that industry is storing wastes in surface impoundments rather than discharging them into flowing surface water. Leakage from these surface impoundments is almost certain, and increased ground-water contamination will result. This problem will be compounded by the growing use of land disposal of waste waters by both industry and municipalities.

Ground-water contamination related to increased underground waste disposal will increase as this method of disposal becomes more popular. Additionally, there will be a greater volume of leaks and spills, although the percentage of total volume actually lost or spilled should remain about the same.

Mining of coal and phosphate, and associated contamination will definitely increase. The extent and impact of contamination by phosphate mining and processing is only little known. It is likely that this will be an area of extensive research over the next five years. Reworking of old tailings will result in the removal of many minerals that could be potential contaminants. The extraction of minerals from deposits which are economically marginal at present-day values will increase as demand for such minerals becomes greater. This will result in new areas of contamination.

Drilling of deep exploratory oil and gas wells will probably increase as will potential ground-water pollution from improperly plugged holes. Brine handling and disposal practices may cause aquifer contamination by surface spills and by disposal in deep wells.

Greater withdrawals of ground water in coastal areas, if allowed, will result in increased salt-water encroachment. Plugging of flowing wells may have long-term beneficial effects by possibly countering salt-water encroachment in some areas. Most states have regulations regarding the plugging of abandoned wells; strict enforcement should favor a decrease in contamination from this source. Additionally, heavy pumping in karst areas may cause surface collapse and subsidence, thereby allowing a wide variety of contaminants to enter the fractures and cavernous carbonate aquifers.

Greater knowledge of the hydraulic connection between lakes and aquifers will favor the preservation of the quality of ground water. Improvements in surface-water quality should lessen the chances of ground-water contamination from surface waters that have moved downward in response to the effects of pumping wells.

Increasing demand for food has caused a need for larger crop yields per acre of land, which will result in larger applications (total and per acre) of fertilizers and pesticides. Hopefully, the incidence of direct pesticide contamination of wells will decrease with better public education and proper training of termite and pest control personnel. Expanding communities will require additional wells located in areas formerly used for agricultural purposes. As in the case of any area being considered for a well field, prior land uses should be taken into account in order to anticipate potential contaminants already in or migrating toward aquifers.

GENERAL RESEARCH NEEDS

Continued studies of the hydrogeologic framework in each state, combined with background water-quality data and an inventory of present and potential sources of contamination, are needed to provide the basis for actions that can reduce the number of problems in the future. Some areas are most susceptible to ground-water contamination from land surface sources; emphasis should be placed on evaluating these areas first.

Not all states in the study area were represented by a case history for each source of contamination in Section VI of this report. Yet, hydrogeologic conditions throughout the region are such that except for regionally limited activities (mining, petroleum development, and the application of highway deicing salts, the potential for contamination is there and agencies responsible for assessing and maintaining ground-water quality should assume that contamination exists and should initiate programs to combat it. For every known leachate-producing landfill and every known leaking impoundment, there are literally hundreds of others that are contaminating ground water in a similar manner, but have not been discovered because no water-quality samples were taken from nearby wells.

Inventory of all actual and potential sources of ground-water contamination is a practice that should be adopted by each state within the region. Techniques, such as aerial photography, remote sensing, and multispectral photography, can be useful. Much scattered data already exist throughout the files of many agencies: septic tank density data; routes of buried pipelines; locations of present and some abandoned mines and oil and gas wells; industrial sites with a listing of products; patterns of distribution of fertilizer and pesticide application; location of sewage and industrial waste lagoons; and major centers of municipal pumping. The last item is most important; in these areas of large ground-water withdrawals, steps should be taken to protect the water supplies. Finally, a review and analysis of presently available ground-water quality data should be conducted to locate water-quality degradation that has already taken place.

Many ground-water contamination sources can be controlled to limit the severity of the problem; salt-water intrusion can be stopped by restricting pumpage; leakage from surface impoundments can be halted by installing suitable lining, and pollutants from spills can be removed by excavating affected soils. However, contamination sources such as existing landfills and the spreading of highway deicing salts are more difficult to deal with.

A better understanding of the uses and purposes of monitoring wells is essential; they are not cures nor protective devices. Placement of monitoring wells at test sites is critical to the evaluation of potential contamination. Inspection of many reports has revealed that the siting of monitor wells was done with a lack of knowledge of the ground-water system. Unfortunately, in these cases, the conclusions derived are at best only partially correct. These methods of monitoring and the conclusions drawn are often published and later used to develop new systems that are equally improper.

More detailed analyses of water samples obtained from wells are needed; most include only non-toxic parameters. Contaminants affecting ground water come from such a wide variety of sources that standard analyses do not truly assess ground-water quality. Selection of constituents for analysis, should reflect local potential sources of contamination and the most common contaminants associated with them.

There appears to have been little or no follow-up on the contamination events discussed as case histories in Section VI. It is assumed that in the majority of the events, unless contamination was massive or critical, little more than a field inspection was conducted by the appropriate state or local agency. Various questions should be asked and appropriate actions taken: what needs to be done; what was done; what caused the event; what should be done to prevent a reoccurrence at the site or elsewhere; who was affected by the contamination and, what was the economic cost as a result of cleanup or loss of water supply due to contamination?

Large national or state agencies seem unable to handle many problems related to ground-water contamination because of a lack of time to study the day-to-day individual local situations. Yet, the public assumes that such agencies were created to handle such problems. Often problems go unresolved except for the incidents which attract widespread attention. It has been stated that this occurs because of insufficient funding to provide the necessary staff; the case may be that funding is adequate but the responsibility and orientation of work is misdirected.

State and Federal agencies can serve to regulate overall activities and solve large-scale problems, but should not be expected to participate in the solution of local problems. Their specialists should be available for advice and assistance, but the resolution of most problems should be at the regional and local levels. Local agencies (water districts, river basin boards, or counties) are more aware of activities within their boundaries and in nearby areas.

Along similar lines, the public agency established to review and comment on environmental impact statements is generally staffed with people of limited experience. Thus, reports often are not subjected to critical review by qualified people. Many projects with the potential for ground-water contamination are approved after improper evaluation. It has been pointed out that "the continued application of such studies can have several effects, including increased prices for natural resources, a declining credibility for environmental science and scientists; a reduction in the overall quality of scientific personnel; and the degradation of our natural resources, not as the result of the direct activities of industry and government, but because of the ineffectual groping of environmental scientists."4)

Another subject that needs consideration is the economic and social assessment of environmental regulations. It is possible for quick judgements and too broad regulations to have a greater adverse effect upon society than contamination of ground water. Socio-economic assessments should consider future society, as well as the present, and the needs of that society.

SPECIFIC NEEDS

Priorities for additional research and control of the principal sources of ground-water contamination in the Southeast are presented in Table 66. Some of these problems, such as salt-water encroachment and petroleum development activities, were recognized long ago and have been extensively researched and are generally presently controlled. Other problems, such as landfills, septic tanks, and leaks and spills, are in need of immediate research and control. New problems, such as surface impoundments, underground storage, and land disposal of waste waters, require anticipatory research and control. Specific needs for additional research, regulation, and control of each source are itemized below.

Surface Impoundments

1. Evaluate surface impoundments as a means of treatment of municipal and industrial wastes in the Southeast versus their potential for causing ground-water quality degradation. Research into soil adsorption-absorption processes and the potential for renovation of the various fluids from the major industries: paper and allied products; petroleum and coal products; primary metals, and chemicals and allied products.

2. Prepare inventories of existing surface impoundments, obtain information on the character of materials being stored, and determine lining conditions and volumes of wastes discharged. Inventories of surface impoundments and public supply wells should be correlated with each other to anticipate possible contamination problems. Approval of future surface impoundments should be considered according to their pollution potential and proximity to water-supply wells.

Table 66. PRINCIPAL SOURCES OF GROUND-WATER CONTAMINATION AND THE PRIORITY FOR ADDITIONAL RESEARCH AND CONTROL IN THE SOUTHEAST.

Sources	Research	Control
Surface Impoundments	I	I
Landfills (urban & industrial)	I	I
Underground Storage of Waste Fluids & Surplus Water	I	I
Leaks & Spills	I	I
Agricultural Activities	II	II
Mining Activities	II	I
Septic Tanks	I	I
Land Disposal of Waste Waters	I	I
Miscellaneous Sources	II	II
Ground-Water Development	II	II
Petroleum Development Activities	III	II
Natural Bodies of Surface Water	II	II
Highway Deicing	III	III

I = High
II = Moderate
III = Low

3. Assess hydrogeological conditions of each proposed, existing, and abandoned surface impoundment area to evaluate potential contamination of ground water.

4. Monitor ground-water quality in the vicinity of surface impoundments and determine liquid losses to the ground-water system from surface impoundments.

5. Develop long-life impervious liners that are better able to withstand attack by impounded material.

6. Research into the treatment required for the various fluids escaping from surface impoundments in which recovery by wells is necessary.

Landfills

1. Prepare industrial and municipal landfill inventories and review the hydrogeologic and physical conditions at each inactive, existing, and planned landfill site to determine possible threats to ground-water quality. Inventory wells located near landfill sites and establish stricter monitoring of the water quality in these wells.

2. Modify existing guidelines governing the siting and design of new landfills as new research findings are brought forth.

3. Increase monitoring of the ground-water quality in the immediate vicinity of landfills. Establish ground-water flow patterns to determine if monitoring wells are properly located.

4. Staff state agencies with hazardous waste sections to deal with such problems. At the end of FY 1975, Florida, Georgia, Mississippi and South Carolina were staffed in such a manner.

5. Define, in each state, hazardous materials by criteria and not name (i.e., define what constitutes toxicity, explosiveness, etc.). In this manner all wastes are classifiable and can be better controlled.

6. Require anyone involved with the generation, transport, and disposal of hazardous waste to submit reports on the nature, volume and destination of the specific materials. These data would provide information on the ultimate fate of hazardous materials.

7. Require pre-treatment of hazardous waste before landfilling when feasible.

8. Enforce regulations prohibiting disposal of toxic wastes in municipal landfills unless approved by a regulatory agency based on site conditions and type of disposed materials.

9. Control industrial disposal sites located on private properties. Many states have little or no control.

10. Increase research into the use and composition of clay and synthetic liners, methods of leachate collection, and processes for treatment of leachate.

11. Increase research on methane gas buildup and elimination of the explosion hazard of such gas generation by proper venting techniques.

Underground Storage of Waste and Surplus Waters

1. Determine areas that are geologically and hydrologically suitable for underground storage of liquid wastes.

2. Assess, in greater detail, the impact on groundwater quality of discharge of excess surface waters and urban storm runoff into drainage wells.

3. Research further into the chemical and biologic reactions between the injected fluids and the receiving fluids and rock. Attention should be given to pressure buildup resulting from gas generation due to breakdown of organics in municipal and industrial waste waters by organisms contained in the receiving waters.

4. Intensify local investigation and data collection for site approval.

5. Assess the effect of pressure buildup and possible reversal of hydraulic gradient in waste injection zones utilized by many injectors.

6. Continue research into the various methodologies available for recharge of treated municipal wastes into shallow and deep aquifers.

7. Research the legal aspects of requiring the injector to pay a fee based in part on the design and type of waste storage site and in part on the volume of waste injected. This fund should accumulate until the site is abandoned by the industry. And, in order to protect the public from the cost of long-term maintenance should the site be abandoned before sufficient funds are available to care for it, injectors could execute a performance bond, the amount of which decreases as the long-term care fund grows.

Leaks and Spills

1. Set up guidelines for reporting spills and initiating clean-up operations to reduce the threat to ground-water quality. Establish public information programs to change attitudes and publicize the reason for reporting spills and to whom the spills should be reported.

2. Establish regulatory task force systems to investigate spills and supervise cleanup.

3. Formulate a more detailed field breakdown of spills to show what is spilled, what portion is recovered from the ground or stream, and how much remains in the ground-water system (potentially or actually) and the surface-water body.

4. Evaluate soil and ground-water conditions along oil, gas and mining product pipelines to assess potential hazard from spills or pipeline breaks, with consideration given to the use of liners in excavations containing buried pipelines and storage tanks bearing substances that can readily degrade or contaminate ground water.

5. Enforce good housekeeping and handling procedures at sites where toxic pollutants and highly mineralized waters can affect ground-water quality.

6. Improve efficiency of monitoring of potential fluid losses, and regulate reporting of tank and pipeline failures.

7. Institute controls and training in hydrocarbon and hazardous material product transfurral, transport, storage and cleanup.

8. Regulate closely the disposal of used oil from service stations and monitoring of gasoline and underground tanks.

9. Increase research into ways to remove hydrocarbons from unconsolidated and rock aquifers and methods of chemical or biological breakdown of hydrocarbons.

10. Increase research of the effects of leaky sanitary and storm sewers on ground-water quality.

Agricultural Activities

1. Investigate the effects of the application of fertilizers, herbicides, and insecticides in urban areas on ground-water quality. The public should be made more aware of the potential for ground-water contamination from improper use of pesticides.

2. Research further the fate of contaminants from application of fertilizers and pesticides in soils overlying recharge zones of regional aquifers.

3. Inventory feedlots and review hydrogeologic conditions at existing and planned feedlot sites to assess the possible danger of ground-water contamination.

4. Evaluate the effect of the use of low-quality irrigation waters on watertable aquifers.

5. Control animal waste lagoons strictly. Determine the sealing or clogging of various soils by organics generated by the lagoons. Consideration should be given to the use of artificial liners where it is obvious that natural sealing will not occur.

6. Prepare fertilizer and pesticide application maps (rate and type) to assess potential impact on ground water.

7. Increase control over persons licensed to apply insecticides for termite and insect control. Personnel in this field need to be made more aware of the potential for ground-water contamination. Training programs should be expanded to include this subject, and they should be assisted by guidelines prepared by soils scientists and hydrogeologist.

Mining Activities

1. Continue research into the control of acid mine drainage, and minimizing leachate from mine tailings by such methods as: grading, revegetation, and surface and subsurface drainage of the disturbed mining areas.

2. Expand research in the field of mineral beneficiation processes to reduce mineral content in tailings, thus cutting back on potential groundwater contamination. Assess the impact of reworking tailings piles.

3. Conduct an inventory of surface and ground-water quality prior to commencement of new mining operations, with an assessment of the impact on ground- and surface-water resources. Studies should also include a definition of the local hydrologic framework and occurrence and movement of ground water.

4. Research and define ground-water contamination from surface and subsurface mining of different minerals.

5. Inventory old mining sites that may serve as sources of ground-water contamination. Many of these sites will be overgrown, but will serve as a means of evaluating the time needed for contaminant levels to decline from the levels observed around active or recently active mines.

Septic Tanks

1. Improve or modify the septic-tank system to provide greater treatment of nutrients and other effluent constituents.

2. Develop criteria for determining septic tank feasibility and proper density in various geologic and hydrologic settings.

3. Research the possibility of additional on-site tests, supplementing the percolation test, to assess the potential for ground-water contamination. Utilization of oxidation-reduction potential (ORP) measurement of ground water underlying a proposed site may be one additional test.

4. Require regional hydrogeologic reports providing such data as depth to bedrock, major joint patterns, soils conditions, and aquifer characteristics, to assist in evaluation of permit applications for septic system where large-scale development is proposed.

5. Consider requiring a developer to provide either, a) public water and septic tanks, or b) private wells and public sewers.

6. Enforce a ban on discharge of hazardous wastes to septic-tank systems at industrial sites.

Land Disposal of Waste Waters

1. Continue evaluation of guidelines presently used to control site selection and the type of waste tolerated where municipal and industrial effluent is applied to the land.

2. Avoid standardizing methods. Individual site evaluation by a multi-disciplinary group should be undertaken to avoid ground-water contamination problems. The assessment of the site suitability and design requires the interaction of geologists, sanitary engineers, hydraulic engineers and hydrologists, agronomists and soil scientists, land planners, water resource planners, and social planners.

3. Increase monitoring of the effects on ground-water quality at existing sites where treated sewage is being disposed of on the land.

4. Supervise and properly maintain active waste disposal sites. This will require trained personnel, with the ability to anticipate problems.

5. Continue research into loading rates (application) of different waste fluids to different types of soils, and assess impact of renovated water on ground-water quality.

Miscellaneous Sources

1. Establish emergency task forces composed of a multi-disciplinary group that would be available to assist in resolving unforeseen contamination events.

2. Explore the possibility of training programs in each state that utilize existing, or proposed, hazardous materials personnel. Training should be by means of hypothetical contamination events or scenarios, attempting to devise the best cleanup procedures in the shortest amount of time.

Ground-Water Development

1. Control the plugging and/or capping of abandoned and flowing wells more effectively.

2. Require the development of multiple aquifers in different zones to be subject to review and regulation.

3. Control well siting and construction practices more uniformly and effectively.

4. Continue control in the coastal region over diversion of ground water in areas susceptible to salt-water intrusion.

5. Research the effects of heavy pumping in karst regions. Study collapse and associated contamination from the point of withdrawal and consider the need to inventory potential contaminant sources prior to extensive development in such areas.

6. Require an environmental impact statement for any large ground-water development.

7. Continue licensing well drillers, on an individual and corporate basis. A licensed driller should be at any job site during periods of active well construction or development.

8. Evaluate rules covering the distance from a well to a potential source of contamination. They are often old rules based on generalized or rule-of-thumb practices without knowledge of hydrologic and geologic controls of ground-water occurrence and movement. In many cases the distance is too little, and in some cases too great.

Petroleum Development Activities

1. Determine further the extent of ground-water quality degradation from petroleum exploration and development activities, including those relating to leaky oil and gas wells, surface impoundments, leaky tanks, etc.

2. Enforce the plugging of abandoned wells using procedures that will actually prevent the inter-aquifer exchange of pollutants.

3. Require filing records of locations of abandoned oil wells, geologic and geophysical holes, together with relevant subsurface and construction details at state environmental agencies, to be available for consultation in the event of a contamination problem in a particular area.

4. Consider joint state and industry programs for selecting abandoned wells for conversion to ground-water monitoring wells.

5. Prohibit the practice of brine disposal through the annulus between the surface casing and the production casing. Such an operation favors corrosion of surface casings and the introduction of brines into fresh-water aquifers.

6. Supervise the plugging and abandonment of petroleum exploration and development holes which might be done more efficiently by environmental agencies than by oil and gas boards.

Natural Bodies of Surface Water

1. Research the possible presence of toxic substances in infiltrated water supplies.

2. Research the ability, over the long term, of natural sediments to reduce concentrations of heavy metals and organic compounds in waters that infiltrate from rivers, lakes, and canals.

3. Review and evaluate the guidelines presently used by hydrogeologists to determine the safety of inducing infiltrated surface water toward wells.

4. Institute studies related to collapse of sinkhole lakes and introduction of contaminants into aquifers.

5. Inventory lakes receiving, intentionally or accidentally, treated sewage wastes and other potential ground-water contaminants.

6. Research the hydraulic relationship between lakes and the various types of aquifers, giving consideration to contaminant movement.

7. Improve surface-water quality, if necessary, wherever surface-water bodies, contribute quantities of water to the ground-water system as a result of pumping by wells.

Highway Deicing Salt

1. Assess the extent of ground-water contamination by highway deicing salts along the major transportation routes in the northern parts of the region.

2. Adopt practices to prevent leaching of salt from salt-storage areas.

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SECTION VIII

APPENDIX A - GLOSSARY OF TERMS

Adsorptive Capacity - Physical limit of adhesion of molecules of gases, or of ions or molecules in solution, to the surfaces of solid bodies with which they are in contact.

Aerobic - Living or active only in the presence of oxygen.

Alkalinity - A measure of the power of a solution to neutralize hydrogen ions expressed in terms of an equivalent amount of calcium carbonate. Alkalinity is caused by the presence of carbonate, bicarbonates, silicates, phosphates, and organic substances.

Alluvium - Clay, silt, sand, gravel, or other rock materials transported by flowing water and deposited in comparatively recent geologic time as sorted or semi-sorted sediments in riverbeds, estuaries, floodplains, and in fans at the base of mountain slopes.

Anaerobic - Living or active in the absence of free oxygen.

Annular Space (Annulus) - The space between casing or well screen and the wall of the drilled hole or between casings of different diameters.

Aquifer - A geologic formation, group of formations, or part of a formation that is water yielding.

Artesian - The occurrence of ground water under greater than atmospheric pressure.

Artesian (Confined) Aquifer - An aquifer overlain by confining beds and containing water under artesian conditions.

Base Flow - The flow of streams composed solely of groundwater discharge.

Biochemical Oxygen Demand (BOD) - A measure of the dissolved oxygen consumed by microbial life while assimilating and oxidizing the organic matter present in water.

Borehole - An uncased drilled hole.

Brackish Water - Water containing dissolved minerals (1,000 to 10,000 mg/l) in excess of acceptable potable water standards, but less than that of sea water.

Brine - A highly mineralized (usually greater than 100,000 mg/l) solution, especially of chloride salts.

Casing - Steel or plastic pipe or tubing that is welded or screwed together and lowered into a borehole to prevent entry of loose rock, gas, or liquid or to prevent loss of drilling fluid into porous, cavernous, or fractured strata.

Chemical Oxygen Demand (COD) - The amount of oxygen, expressed in milligrams per litre, consumed under specific conditions in the total oxidation of organic and oxidizable inorganic matter in waste water, corrected for the influence of chlorides.

Chemical Water Quality - The nature of water as determined by the concentration of chemical constituents.

Coliform Group - Group of several types of bacteria, some of which (fecal) are found in the alimentary tract of warm-blooded animals. Fecal coliform are often used as an indicator of animal and human contamination of water.

Concentration - The weight of solute dissolved in a unit volume of solution.

Cone of Depression - The depression, approximately conical in shape, that is formed in a water-table or potentiometric surface when water is removed from an aquifer.

Confining bed - A saturated, but poorly permeable bed, formation, or group of formations that impedes ground-water movement and does not yield water freely to a well or spring. However, a confining bed may transmit appreciable water to or from adjacent aquifers, and where sufficiently thick, may constitute an important ground-water storage unit. Used synonymously with aquiclude and aquitard.

Connate Water - Water that was deposited simultaneously with the sediments, and has not since then existed as surface water or as atmospheric moisture.

Consumptive Use - That part of the water withdrawn that is no longer available because it has been either evaporated, transpired, incorporated into products and crops, or otherwise removed from the immediate water environment.

Contamination - The degradation of natural water quality as a result of man's activities, to the extent that its usefulness is impaired. There is no implication of any specific limits, since the degree of permissible contamination depends upon the intended end use, or uses, of the water.

Crystalline Rock - A general term for igneous and metamorphic rocks as opposed to sedimentary rocks.

Curie - The quantity of any radioactive material giving 3.7 x 1010 disintegrations per second. A picocurie is one trillionth (10^{-12}) of a curie, or a quantity of radioactive material giving 2.22 disintegrations per minute.

Degradable - Capable of being decomposed, deteriorated, or decayed into simpler forms with characteristics different from the original. Also referred to as biodegradable when readily decomposed by organisms.

Degradation of Water Quality - The act or process of reducing the level of water quality so as to impair its original usefulness.

Drainage Well - A well that is installed for the purpose of draining swampy land or disposing of storm water, sewage, or other waste water at or near the land surface.

Drawdown - The lowering of the water table or piezometric surface caused by pumping or artesian flow.

Effluent - A waste liquid, in its natural state or partially or completely treated, that discharges into the environment.

Evapotranspiration - The combined processes of evaporation from land, water, and other surfaces, and transpiration by plants.

Fall Line - A line joining the waterfalls on a number of successive rivers that marks the point where each river descends from the upland (Piedmont) to the lowland (Coastal Plain).

Feedlot - A relatively small, confined land area for raising and fattening cattle.

Greensand - A sedimentary deposit consisting, when pure, of grains of the mineral glauconite.

Ground Water - Water beneath the land surface in the saturated zone that is under atmospheric or artesian pressure. The water that enters wells and issues from springs.

Ground-Water Reservoir - The earth materials and the intervening open spaces that contain ground water.

Grout - To fill, or the material filling, the space around the pipe in a well, usually between the pipe and the drilled hole. The material is ordinarily a mixture of Portland cement and water.

Hardness - A property of water caused by the presence of calcium and magnesium, which is reflected in the amount of soap necessary to form suds and produces incrustation in appliances and pipes when the water is heated. It is expressed as an equivalent amount of calcium carbonate.

Hazardous Waste - Any waste or combination of wastes (which pose a substantial present or potential hazard to human health or living organisms) whose properties include flammability, evolution of toxic or irritating vapors, contact irritation, or human or animal toxicity.

Heavy Metals - Metallic elements, including the transition series, which include many elements required for plant and animal nutrition in trace concentrations, but which become toxic at higher concentrations. Examples are: mercury, chromium, cadmium, and lead.

Hydraulic Conductivity - The quantity of water that will flow through a unit cross-sectional area of a porous material per unit of time under a hydraulic gradient of 1.00 at a specified temperature.

Hydraulic Gradient - The change in static head per unit of distance along a flow path.

Igneous Rock - Rock formed by the solidification of molten material that originated within the earth.

Infiltration - The flow of a liquid into soil or rock through pores or small openings.

Injection Well (Disposal Well) - A well used for injecting fluids into an underground stratum.

Ion Exchange - Reversible exchange of ions absorbed on a mineral or synthetic polymer surface with ions in solution in contact with the surface. In the case of clay minerals, polyvalent ions tend to exchange for monovalent ions.

Iron Bacteria - Bacteria capable of oxidizing ferrous iron to ferric iron as part of their metabolic process.

Karst - A limestone plateau marked by sinks, or karst holes, interspersed with abrupt ridges and irregular protuberant rocks, usually underlain by caverns and underground streams.

Lagoon - A shallow pond, usually man-made, to treat or store municipal or industrial waste water.

Leachate - The liquid that has percolated through solid waste or other man-emplaced medium and has extracted dissolved or suspended material from it.

Lignite - A brownish-black coal in which the alteration of vegetal material has proceeded further than in peat but not so far as sub-bituminous coal.

Lysimeter - An instrument for measuring the water percolating through soils and determining the materials dissolved by the water.

Metamorphic Rock - A rock which has been altered by heat or intense pressure, causing new minerals to be formed and new structures in the rock.

Milligrams Per Litre - The weight in milligrams of any substance contained in one litre of liquid. Approximately equivalent to parts per million when the liquid is water.

Mineralization - Increases in concentration of one or more constituents as the natural result of contact of ground water with geologic formations.

Nonpoint Source - A source from which the contaminant enters the receiving water in an intermittent and/or diffuse manner.

Nutrients - Compounds of nitrogen, phosphorus, and other elements essential for plant growth.

Organic - Being, containing, or relating to carbon compounds, especially in which hydrogen is attached to carbon, whether derived from living organisms or not; usually distinguished from inorganic or mineral.

Oxidation - A chemical reaction in which there is an increase in positive valence resulting from a loss of electrons; in contrast to reduction.

Percolation - Movement under hydrostatic pressure of water through unsaturated interstices of rock or soil.

Permeability - A measure of the capacity of a porous medium to transmit fluid.

Piezometric Surface - The surface defined by the levels to which water under artesian conditions will rise in tightly cased wells. Also called potentiometric surface.

Plume - A body of contaminated ground water originating from a specific source and influenced by such factors as the local ground-water flow pattern, density of contaminant, and character of the aquifer.

Point Source - Any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, or concentrated animal feeding operation from which contaminants are or may be discharged.

Pollutants - Substances that may become dissolved, suspended, absorbed or otherwise contained in water, and impair its usefulness.

Pollution - The degradation of natural water quality, as a result of man's activities, to the extent that its usefulness is impaired.

Pore - An open space in rock or soil.

Porosity - The relative volume of the pore spaces between mineral grains in a rock as compared to the total rock volume.

Primary Treatment (Sewage) - The removal of larger solids by screening, and of more finely divided solids by sedimentation.

Recharge - The addition of water to the ground-water system by natural or artificial processes.

Reduction - A chemical reaction in which there is a decrease in positive valence as a result of gaining of electrons.

Runoff - Direct or overland runoff is that portion of rainfall which is not absorbed by soil, evaporated or transpired by plants, but finds its way into streams as surface flow. That portion which is absorbed by soil and later discharged to surface streams is ground-water runoff.

Salt-Water Intrusion (or Encroachment) - Movement of salty ground water so that it replaces fresh ground water.

Saturated Zone - The zone in which interconnected interstices are saturated with water under pressure equal to or greater than atmospheric.

Sedimentary Rock - Rocks formed by the accumulation of sediment.

Sludge - The residue resulting from waste-water treatment which also produces a liquid stream (effluent).

Solution Channels (holes or cavities) - Fractures, joints, bedding planes, or other planar openings in soluble rocks, such as limestones which have been enlarged, particularly at intersections of these planes, by moving, slightly acid ground water.

Sorption - A general term used to encompass processes of adsorption, absorption, desorption, ion exchange, ion exclusion, ion retardation, chemisorption, and dialysis.

Specific Conductance - The ability of a cubic centimetre of water to conduct electricity; varies directly with the amount of ionized minerals in the water.

Subsidence - Surface caving or distortion brought about by collapse of deep mine workings or cavernous carbonate formations, or from overpumping of certain types of aquifers.

Surface Water - That portion of water that appears on the land surface, i.e., oceans, lakes, rivers.

Toxicity - The ability of a material to produce injury or disease upon exposure, ingestion, inhalation or assimilation by a living organism.

Transmissivity - The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

Unsaturated Zone (Zone of Aeration) - Consists of interstices occupied partially by water and partially by air, and is limited above by the land surface and below by the water table.

Upconing - The upward migration of ground water from underlying strata into an aquifer caused by reduced hydrostatic pressure in the aquifer as a result of pumping.

Water Quality - Pertaining to the chemical, physical and biological constituents found in water and its suitability for a particular purpose.

Water Table - That surface in an unconfined ground-water body at which the pressure is atmospheric. It defines the top of the saturated zone.

Water-Table Aquifer - An aquifer containing water under atmospheric conditions.

Weathered Zone - Thickness of rock which has been subjected to a group of processes, such as the chemical action of air and rain water, of plants and bacteria, and the mechanical changes resulting from temperature fluctuations, whereby rock on exposure to the weather changes in character, decays, and finally crumbles into soil.

SECTION VIII

APPENDIX B - ABBREVIATIONS

10^6 = million
10^9 = billion
10^{-6} = millionth
acre-ft = acre-foot
bbl = barrel (oil or brine, 42 gal)
bgd = billion gallons per day
BOD = Biochemical oxygen demand
Ca = calcium
$CaCO_3$ = calcium carbonate
Ci = curie
Cl = chloride
cm = centimetre
CO_2 = carbon dioxide
COD = chemical oxygen demand
cu cm = cubic centimetre
cu ft = cubic foot
cu hm = cubic hectometre
cu m = cubic metre
F = fluoride
ft = foot
g = gram
gal = gallon
gpd = gallons per day
gpm = gallons per minute
ha = hectare
hm = hectometre
in = inch
kg = kilogram
km = kilometre
l = litre
lb = pound
l/s = litre per second
m = metre
mCi = millicurie
mgd = million gallons per day
mg/l = milligrams per litre
mi = mile
ml = millilitre
mm = millimetre
N = nitrogen
NH_3 = ammonia
NO_2 = nitrite
NO_3 = nitrate
NO_3-N = nitrate nitrogen

OH = hydroxide
pCi = picocurie
PO_4 = phosphate
ppb = parts per billion
ppm = parts per million
psi = pounds per square inch
Ra = radium
Rn = radon
s = second
sq cm = square centimetre
sq ft = square foot
sq m = square metre
sq km = square kilometre
sq mi = square mile
TDS = total dissolved solids
TOC = total organic carbon
yd = yard
yr = year
^{o}C = degrees Celsius
^{o}F = degrees Fahrenheit
µg/l = micrograms per litre

SECTION VIII

APPENDIX C - CONVERSION FACTORS

Basic Metric Units

metre measures length
gram measures mass
litre measures volume

Metric Prefixes

mega	1,000,000	centi	0.01
kilo	1,000	milli	0.001
hecto	100	micro	0.000001
deka	10	nano	0.000000001
deci	0.1	pico	0.000000000001

To convert	into	Multiply by
centimetres	inches	0.3937
cubic metres	cubic feet	35.31
	gallons	264.2
	barrels	6.29
cubic hectometres per day	billion gallons per day	0.2642
	million gallons per day	264.2
cubic metres per second	million gallons per day	4.386×10^{-2}
	cubic feet per second	2.831×10^{-2}
grams	pounds	2.205×10^{-3}
hectares	acres	2.471
kilograms	pounds	2.205
kilograms per square centimetre	pounds per square inch	14.22

To convert	into	Multiply by
kilometres	miles (statute)	0.621
litres	gallons	0.2642
litres per second	cubic feet per second	3.53×10^{-2}
	gallons per minute	15.85
	acre-feet per day	7.042×10^{-2}
metres	feet	3.281
micrograms per litre	parts per billion	1.0
milligrams per litre	parts per million	1.0
millimetres	inches	3.937×10^{-2}
square centimetres	square inches	0.155
square kilometres	acres	247.1
	square miles	0.3861
square metres	square feet	10.76
tonnes	tons (short)	1.10

SECTION VIII

APPENDIX D - WATER-QUALITY STANDARDS

The levels of mineralization or contamination which can be tolerated in ground water are dependent upon the intended use for the supply. Recommended water-quality standards are available for agricultural, industrial, and public-supply needs. Certain chemical constituents can be tolerated through a wide range of concentrations without adverse effects even in stringent cases requiring excellent water quality, while other constituents can be acceptable only at a minute levels or not at all. The water-quality standards for any particular use are varied and in most cases well documented. It is evident that to list each and every guideline is beyond the scope of this report.

The U. S. Environmental Protection Agency has National Interim Primary Drinking Water Standards for certain constituents and is currently in the process of updating the 1962 Public Health Service recommended limits for others. The new standards and the 1962 recommended limits are shown in the following two tables.

U. S. PUBLIC HEALTH SERVICE CHEMICAL STANDARDS OF DRINKING WATER, 1962.

Recommended maximum allowable concentrations
where other more suitable supplies are, or
can be made available:

Substance	Concentration in mg/l
Alkyl Benzene Sulfonate (ABS)	0.5
Arsenic (As)	0.01
Chloride (Cl)	250
Copper (Cu)	1
Carbon Chloroform Extract (CCE)	0.2
Cyanide (CN)	0.01
Iron (Fe)	0.3
Manganese (Mn)	0.05
Phenols	0.001
Sulfate (SO_4)	250
Total Dissolved Solids (TDS)	500
Zinc (Zn)	5

U. S. ENVIRONMENTAL PROTECTION AGENCY NATIONAL INTERIM PRIMARY DRINKING WATER STANDARDS, DECEMBER, 1975.

Maximum contaminant level which shall
constitute grounds for outright
rejection of the supply:

Substance	Concentration in mg/l
Arsenic (As)	0.05
Barium (Ba)	1
Cadmium (Cd)	0.01
Total Chromium (Cr)	0.05
Fluoride (F)	1.4 to 2.4[a]
Lead (Pb)	0.05
Mercury (Hg)	0.002
Nitrate (as N)	10
Selenium (Se)	0.01
Silver (Ag)	0.05

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a) Varies with annual average of maximum daily air temperature.